This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

3 3433 06642537 6

THE WORKING OF THE

STEAM ENGINE EXPLAINED

BY THE USE OF THE

INDICATOR:

OR, AN EXPOSITION OF THE BEST MEANS OF PRODUCING THE GREATEST EXPLOSIVE EFFECT FROM A GIVEN QUANTITY OF STEAM-POWER, WITH THE LEAST EXPENDITURE OF FUEL.

WITH A DESCRIPTION OF

The Mode of Expanding Steam and the Compounding of Engines.

FROM THE COPELAND LIBRARY
Mechanical Engineers
American Society

BY JOSEPH HOPKINSON,

Of the firm of Hopkinson & Co., Engineers, Huddersfield.

Illustrated with Engravings and Diagrams.

"What the Stethoscope is to the Physician, the Indicator is to the skilful Engineer—revealing the secret workings of the inner system, and detecting minute derangements in parts otherwise remote."

Fourth Edition, Enlarged and Improved.

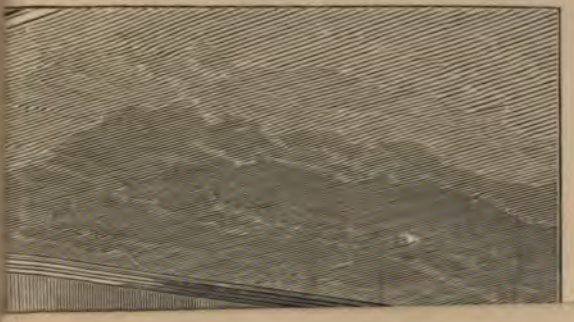
LONDON:
JOHN WEALE, HIGH HOLBORN.
MANCHESTER: THOMSON AND SON. HUDDERSFIELD: B. BROWN.
1863.

NEW YORK PUBLIC LIBRARY

THE NEW YORK
PUBLIC LIBRARY
591532 A
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R 1932 L

B. BROWN, PRINTER, MARKET PLACE CORNER, HUDDERSFIELD

H 6 r



ГОСУДАРСТВО ПУБЛИЧНАЯ

PREFACE.

THREE Editions of this Work, each of the two last considerably enlarged upon the other, having been disposed of, and that, too, much more rapidly than had been anticipated, the Author has great pleasure in submitting another Edition, still further enlarged, and, as he also flatters himself, greatly improved in many particulars; for as time proceeds, experience and knowledge is gained.

The design of the Author from the first has been, by means of homely language accompanied with familiar and practical illustration, to instruct those who are entrusted with the care and management of Steam Engines in the use and advantages of the *Steam Engine Indicator*—it being alone through the instrumentality of that unerring test, that they can ascertain with certainty whether they are deriving the greatest amount of practical advantage from the several quantities of impulsive power they may generate and apply. Interspersed with these

instructions he has given hints and examples, intended to shew how practical improvements in the working of most Steam Engines may be effected at little cost, to the great saving of fuel, and the steady and uniform application of the motive power—both these being points of manifest importance to the proprietors of Steam Engines, and of advantage to the practical Engineer. The conclusions recorded in this Work have been arrived at from observation and study, not in the closet, but in company with the Steam Engine in its various stages and alterations: and although the mere theorist, or the scientific literary writer, may object to the plain and simple manner in which the different topics descanted on is treated, the Author is assured, from the difficulties which in the early period of his own experience he himself had to contend with and overcome, that his plan of procedure is the best that he could possibly have adopted for the accomplishment of his main object in undertaking the Work—the instruction of the practical *working* Engineer.

The sections of the Work devoted to the questions of EXPANSION OF STEAM and the COMPOUNDING OF

Steam Engines, with the examples adduced, shew how these are to be effected in the most available manner with the best practical results, and will, it is believed, be found to be of value to those for whom they are designed. There have been widely different opinions amongst Engineers on this subject, and particularly on the proportions of cylinders to each other, according to pressure. The Author knows of nothing hitherto published which imparts the information on these important subjects he has here endeavoured to convey. Yet these are the real questions of the day—the main direction in which further improvement of the Steam Engine is to be sought. Economy in the working of the Steam Engine is known to be in the application of *high pressures.* The higher—within the limits of safety—we can get, the more economical. To obtain the whole benefit of high steam, we must apply the principles of Expansion and Compounding, beginning with the highest pressure of steam we have, and parting with it at the lowest possible pressure. How this is to be accomplished with practical advantage, the Author has endeavoured to indicate.

The Examples given from various Engines will be found useful to working Engineers and proprietors of Steam Engines, for comparisons. They will also, it is hoped, serve as a means of stimulating to a sense of the importance of keeping pace with the improvements of the day.

The Tables appended to the Work will, it is also believed, be found to be of service to the practical Engineer, aiding him in his calculations for various matters connected with the Steam Engine and its working. In those Tables, and, indeed, throughout the Work, decimals have been, to a great extent, dispensed with, and also fractional parts, with the exception of those expressed by the common signs $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$—the calculations when so reduced and expressed, being near enough for all practical purposes, and more intelligible to a large portion of the class for whom the Work is designed. In fact, throughout the treatise, the aim of the Author has been to express himself in simple phraseology; and though his production may not possess the charm of literary embellishment, he trusts that it may be found at least to possess the merit of perspicuity in the treatment of a

dry subject, and to be of practical utility. The rapid sale of three Editions, and the urgent call for another, justifies the last conclusion, without it is hoped, the appearance even of presumption.

The commendatory opinions expressed to the Author by individuals of eminence in the Engineering profession, and by distinguished owners of the most powerful and best wrought Steam Engines ever constructed, regarding the manner in which he has imparted information and conveyed instruction on a subject which concerns the national well-being, has been to him a source of high gratification. If what he has done in this direction shall in any degree be instrumental in adding to the value and efficiency of the great motive-power of our manufactories, mines, ships, and railroad locomotion, he will feel himself amply rewarded by the conscious satisfaction that his endeavours to that end have not been in vain. In that spirit he has laboured to make himself practically acquainted with the important and additional facts which he here ventures to lay before those interested in the economical and efficient working of the Steam Engine, with such observations upon, and deductions

from those facts, as to him seem necessary for a popular understanding of the subject; and in that spirit he leaves what he has thus attempted in the hands of the parties for whose benefit the Work is intended.

BRITANNIA WORKS,
HUDDERSFIELD, JAN., 1863.

CONTENTS.

PAGE.

HISTORY of the Steam Engine Indicator... 1
General Description of the Use and Advantages of the Instrument 5
Description of the Construction of the Indicator 8
Instructions how to Affix and Use the Indicator 13
Description how Diagrams are formed by the Instrument, with example 15
The Vacuum of a Steam Engine defined 21
Nominal and Indicated Horse Power of Steam Engines 30
Expansion of Steam—general description and advantages... ... 36
Rule, to find the Power of a Steam Engine on the basis of Watt's definition 44
How to ascertain the Friction of an Engine 45
Explanation of the Figuring of Diagrams 46
Rule to ascertain the Power required to drive any quantity of Machinery : or the Power the Engine is exerting 48
Rule to ascertain the quantity of Fuel consumed per hour per Horse Power 51
Advice to Engineers 52
Engineers should be Inspectors of their own Engines 53

THE CONSTRUCTION AND ACTION OF STEAM ENGINE VALVES :— 55

Illustration of a Three-port Valve without "Lap" 56
"Lap" or Cover of a Three-port Slide Valve... 60
Illustration of ditto ditto 61
The D Slide Valve 66
Illustration of "Lap," or Cover, of the D Valve, with Eccentric Crank and Rock Shaft 67
Enlarged Section of Engine Cylinder with D Valves... ... 70
The Cornish or Double-beat Drop Valves 72
Illustration of Side-pipes and Cornish Valves 73
Elevation of Side-pipes and Cylinder with Cornish Valves ... 75
Expansion Drop Valves 77

Equilibrium Drop Valves 78
Expansion Slide Valves 79
Revolving Expansion Valves 81

EXPLANATION OF DIAGRAMS :— 85

Large Steam-ways 87
Additional Exhaust Valve 87
Injurious effect of small Steam-ways and Pipes 89
Great noise in the Condenser sometimes mistaken for a good Vacuum 90
Effects of the Atmosphere upon the Air-pump 92
Contracted Thoroughfares and Valves 94
Steam too late and Exhaust too late, and the Exhaust closed too soon 96
Imperfect Valve-setting detected by the Indicator 99
D Valves without "Lap," and High-pressure Steam... ... 100
D Valves without "Lap," with a Revolving Expansion Valve added 102
Examples of derangement of Valves 105
Imperfect Valve-setting detected by a true Indicator ... 106
Example of Valves with too much Lead 107
Imperfect Valve-setting the cause of Break-downs 109
Example of Increased power from proper Adjustment of Valves 112
Difference of Indicators 113
Vertical Revolving Tappets, with Hoop Valves 115
Increase of Power and less Consumption of Fuel by good management 116
Zig-zag Diagram caused by the Valves of the Engine opening too quickly 119
Steam Wasted for want of being worked more Expansively... 120
No Zig-zag Diagrams where the Valves are properly set ... 121
The difference between small and large Indicators 123
Engine Breaking-down from the Valves having too much Lead 124
Different Diagrams by the same Indicator from different Engines 125
Illustration of deranged Valves 128
Too much Lead of Valve and large Steam-ways the cause of Engines Breaking-down 131
Illustration, how to admit the Steam on easily with the Slide Valve 133
How to make the most of the Steam 135

EXAMPLES FROM VARIOUS ENGINES :—

Double Diagram from Engine with Expansion and Slide Valves 136
Large Steam-ways and large Condenser 138
Nominal and real Power of Engines 139
Examples from HORNSLOWER'S Compound Engine 140
A D Valve having the edge Square, or Straight across ... 142
Throttle Valve too large, causing the Engine to jump and start 144
The Steam too early at the beginning of the stroke 145
Diagrams from the Engines of Messrs. T. SALT & SONS, of Saltaire 148
Diagram from the Engine of Messrs. JOHN SHAW & SONS, of Stainland 150
Governor regulating the Cutting-off the Steam 150
Contrast to Rule-of-thumb management 153
Full-sized Diagram, and a Report of a Boiler Inspector ... 153
Boiler Inspector's Report exposed by the silent lines of the Indicator 154
Broken connecting-rod of D Valves 157
Alteration of a 40-horse Condensing Engine from D Valves to Short Slides 158
Diagram from a pair of Direct-acting Vertical Engines with D Valves 159
D Valves made to Cut off at any portion of the stroke by ordinary arrangement 161
Example of Valve-box being too short—not allowing of extra "Lap," or Traverse 162
Double Diagram—example of even Valve-setting 164
Example from Messrs. GEO. ANDREW & SON'S Compound Engine 165
Diagram from another Engine under other management ... 169
Illustration of the too common saying—"He is all right" ... 170
Full-sized Diagram and Report from the Manchester Steam Boiler Association 171
The superiority of HOPKINSON'S Indicator demonstrated ... 173
Report of the Oldham Engineers' Association on HOPKINSON'S Indicator 178
Example of Valve-setting from Messrs. WORTHINGTONS', of Hollingwood 179
Example of Fuel saved by proper Valve-setting, at Messrs. G. MEIGH & SON'S, Staffordshire 181

The "British Queen" Steam-ship, with HALL's Surface Condenser 185
Diagrams from the Engines of the "Great Britain" Steam-ship, before and after alterations 186
How to contract the thoroughfares of an Engine, where the Valve-box is too short, instead of Lapping the Valve ... 190
The "Great Eastern" Steam-ship 194
HOPKINSON's letter to the *Mechanics' Magazine*, on the Explosion of the flue-case of the "Great Eastern" ... 196
Diagrams from the "Great Eastern" Paddle Engines ... 199
Ditto Ditto Screw Engines ... 204
Remarks on the state of the Engines of the "Great Eastern" 206

WORKING STEAM EXPANSIVELY :— 211

Rule and Illustration to ascertain the Pressure of the Steam, at any portion of the Stroke 212
Diagram, giving line of Expansion 215
Table shewing the quantity of Steam used when worked without Expansion and the Power obtained; also the quantity when worked Expansively, varying from $\frac{7}{8}$ to $\frac{1}{8}$ the cut-off, and the Pressure at the termination of the Stroke ... 216

GENERAL OBSERVATIONS ON THE COMPOUNDING OF STEAM ENGINES :—

Difference of the Area of the Cylinders of Compound Engines 218
The Fallacy that the Cylinders of Compound Engines should be of equal Area 220
The same Power obtained by Expanding the Steam in one Cylinder as is obtained with Compounding, with the same quantity of Steam 221
A Table shewing the difference in strain from Compounding, contrasted with Expansion in one Cylinder 222
Messrs. ROBERTON's Patent plan of Compounding Steam Engines 224
WOLFE's plan of Compounding 225
Separate High-pressure Engines exhausting into Low-pressure 226
Compounding Beam Engines by a Steam Cylinder at each end of the Beam 228
Example from Messrs. POTTER & Co.'s Compound Beam Engine 229
Compound Beam Engines converted into Condensing Engines 231
Diagram from Messrs. NEILD & SON's Engine; the Compound principle being dispensed with 235

The Compounding of Engines re-patented by McNaught ... 237
Re-patenting known plans and principles 241
Single Cylinder High-pressure Engine working stroke for stroke with a Condensing Engine 243
A Compound Engine with the High-pressure Cylinder of larger area than the Condensing Cylinder 246
Injurious effects of ditto 249
Mode of Alteration—converting both Cylinders into Condensing ones, with one Condenser and one Air-pump 252
Benefit therefrom 253
Example of Compounded Engines, working stroke for stroke 254
On Compounding of Non-condensing Engines 258
Working Steam in two Cylinders—first, the High-pressure Cylinder; thence to a Boiler; and thence into a Low-pressure Cylinder 261
Non-condensing High-pressure Engines Expanding the Steam in one Cylinder 264
Example 266
Letter from a practical Engineer on the same... 267
Direct-acting Horizontal Condensing Steam Engine 270
Example, with Plates 271
Direct-acting Engines compared with the Beam Engine ... 271
Messrs. Petrie & Co.'s letter, advocating the Beam Engine 272
Comments thereon 273
Novelties in the Construction of a Direct-acting Horizontal Condensing Engine 278
Directing-acting Horizontal Compound Steam Engine ... 285
Example from a Direct-acting Horizontal Condensing Engine 289
On the setting of Steam Engine Valves 292
Examples 293
Examples of D Valves... 295
A Table shewing the amount of "Lap" required for Slide Valves, when the Steam is to be worked Expansively ... 296
Two Engines Coupled, working at right angles 299
Proportion of a pair of 28 nominal horse-power Condensing Beam Engines, shewing the mode in which the Valves are set 302
Steam Engines work as they are set—good or bad 303
Short and Long-stroked Engines 304
Cased Cylinders 306
Throttle Valves 311
Metallic Packings for Piston and Stuffing-boxes 315
Feeding Steam Boilers with Water... 317

ON THE MANAGEMENT OF THE STEAM ENGINE AND BOILER :—

Duties of the Engineer 319
The Boiler 319
The Furnace 326
The Engine : Rules and Examples 332
How to calculate from a Diagram the quantity of Steam used by a Steam Engine 338
How to calculate the effective Pressure of Steam on the Piston at the end of the stroke, cut off at any distance, when worked Expansively 340
Table shewing the Increase and Decrease of the strength of Iron at various temperatures 342
Table of the Expansion of Air by Heat 344
Strength of Iron Bars and Boiler Plates 345
Extracts from a Paper read before the British Association on the Construction of Steam Boilers 348
Table of Strength of Wrought Iron Bars and Plates 352
Rule for Calculating the Strength of Cylinders or Boilers as generally applied 355

THE SAFETY VALVE :— 356

Rule to ascertain at what Pressure a Safety Valve is Weighted 365
Final Hints regarding the Indication of Steam Engines 366

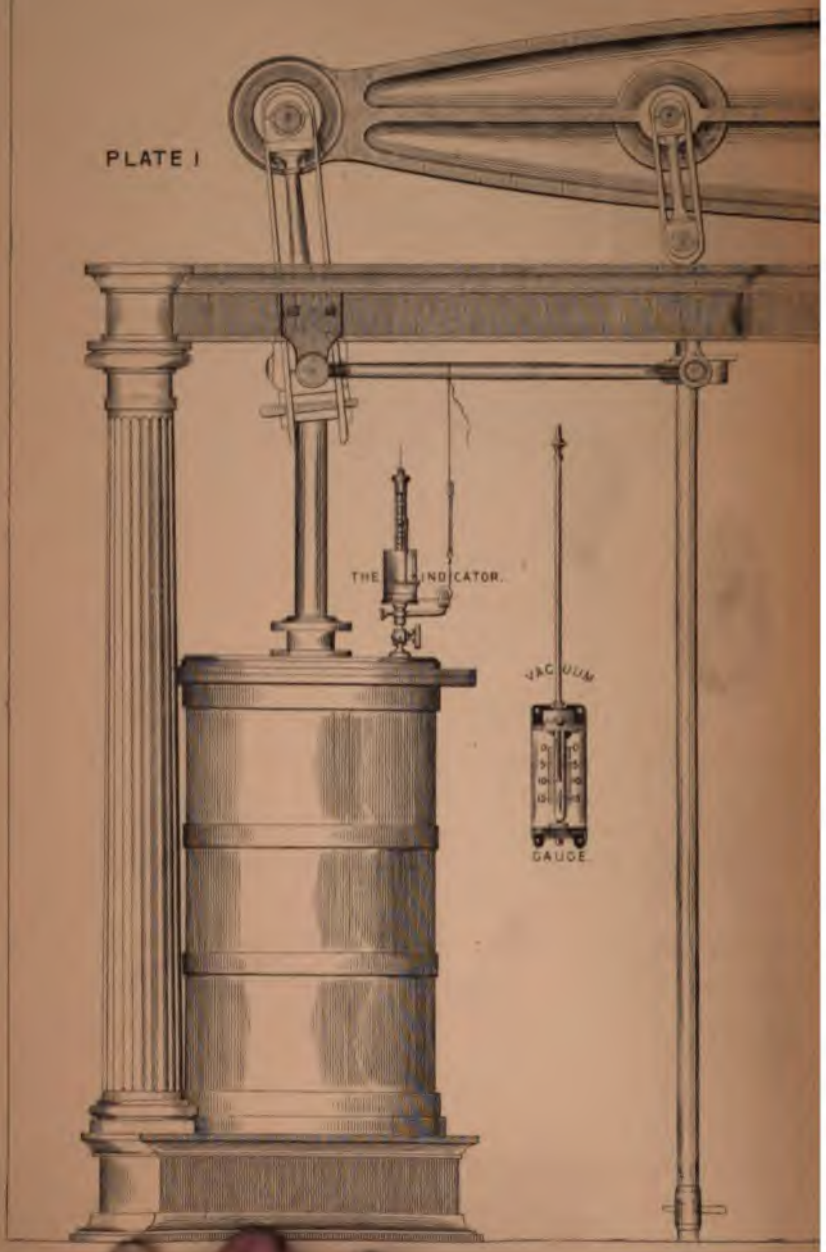
APPENDIX:

CONTAINING TABLES AND OTHER INFORMATION CALCULATED TO BE OF SERVICE TO ENGINEERS, AND OTHERS ENTRUSTED WITH THE MANAGEMENT OF THE STEAM ENGINE.

	PAGE.
A Table shewing the quantity of Fuel consumed in proportion to the Pressure of Steam to produce equal power, when worked Expansively	III.
A Table, shewing the average Pressure of Steam upon the Piston throughout the stroke, when cut off in the Cylinder from $\frac{1}{3}$ to $\frac{11}{12}$, commencing with 10lbs and advancing in 5lbs up to 150lbs Pressure, with explanation	IV.
Imperial Standard Measures	VIII.
Rule to ascertain the Weight of Cast-iron Balls	X.
Boiling Point of Water	X.
Geometry	X.
Weight of Cast-iron Balls, from 3 to 13 inches in diameter, useful for Safety Valves, &c.	XI.
Weight of Cast-iron Plates per superficial foot, as per thickness	XI.
Weight of Boiler Plates	XII.
Weight of square Bar-iron	XII.
Weight of round Bar-iron	XIII.
Weight of Sheet Lead per superficial foot	XIII.
Weight of Cast-iron Pipes, 1 foot in length, and from 3 to 24 inches in diameter	XIV.
Weight of Materials	XV.
Table shewing the difference in the Strength of Metals ...	XVI.
Heat-conducting Powers of different Metals	XVI.
A Table shewing the temperature Metals melt at	XVI.
A Table for Safety Valves, Cylinders, Air-pumps, &c., containing the Circumferences and Areas of Circles, from $\frac{1}{16}$ of an inch to 10 inches, advancing by $\frac{1}{16}$ of an inch; and by $\frac{1}{8}$ of an inch from 10 inches to 100 inches diameter ...	XVII.

A Table containing the Circumferences and Areas of Circles, from 8 to 30 feet, advancing by 1 inch at a time ... xxix.
A Table shewing the Pressure of Steam, from 2½lbs up to 60lbs, and the Weight of a column of Mercury, and the Number of feet and inches of Water in a column at the different Pressures .. .. xxxiii.
A Table shewing the Temperature of Steam at different Pressures, from 1lb per square inch to 240lbs, and the quantity of Steam produced from a cubic inch of water according to Pressure ... ... xxxiv.
A Table shewing the Weight of Water in Pipes of various diameters, 1 foot in length ... ... xxxvi.
A Table shewing the Weight Cylindrical Columns of Cast-iron will bear with safety, by Tredgold ... . xxxvii.
Durable Cement for Steam and Water Joints, Gas Retorts, &c. xxxviii.
Useful Cement for Reservoirs, Cisterns, Wells, Water-courses, &c. ... ... xxxviii.
Glossary ... ... xxxix.

PLATE I



THE

STEAM ENGINE INDICATOR.

HISTORY OF THE INSTRUMENT.

THE INSTRUMENT known by the name of the *Steam Engine Indicator* was invented by the celebrated JAMES WATT, a man whose name is indelibly associated with the improvement of the Steam Engine. The genius of WATT, combined with the facility of practical application possessed by him in an eminent degree, enabled him to become one of the greatest promoters of civilisation, by placing at the command of his species a motive power for manufacturing and industrial operations almost illimitable. Having, by his improvements, created as it were this new motive power,—the Steam Engine,—an instrument to enable him to measure the definite amount of the power of each Engine, and to indicate defects

in construction or working, became to him an indispensable requirement. To supply that want he devised what is at present known as the *Steam Engine Indicator*. For a considerable period WATT kept the knowledge of that useful instrument to himself: but having at length to send a Steam Engine abroad, and the responsibility of its erection and proper working devolving upon the firm of which WATT was a member, he furnished a mechanic, whom he sent out to superintend the erection of that Engine, with an *Indicator*, having previously instructed him in the art of its application; shewing him that by its aid he could set the valves of the Engine so as to produce the greatest effect from a given quantity of impulsive power. It was to this circumstance that the Engineering profession are indebted for this most valuable instrument; for as will readily be imagined, a knowledge of the important aid it was calculated to render to the practical mechanic having been thus imparted, it could not long be kept secret, as WATT had hitherto kept it.

Since the period we speak of, the *Steam Engine Indicator* has received several minor but important improvements. In principle, it is as it left the hands of WATT: it is only in detail where alterations and improvements have been made. Mr. SOUTHERN, an ingenious mechanic in Messrs. BOULTON and WATT's service, added the revolving cylinder with its attached paper and pencil, in place of the former traversing board, to enable the instrument to "register its own observations." Some makers have this revolving cylinder detached, or apart, from the other portions of the instrument; but Messrs. HOPKINSON find by experience,—the test of all improvement,—that it is best

to have the revolving cylinder placed upon the steam cylinder of the *Indicator*, because it is in that place the most convenient and firm for the operation which has to be performed upon it. The pencil holder should be parallel to the cylinder piston, as by that mode the instrument is rendered the most sensitive, and, as a necessary consequence, the most correct indications are obtained. This improvement though a minor one in appearance, will hereafter be shewn to be of considerable importance. The difference of the indications given by this instrument will be shewn by contrasting its diagrams with those given by that description of instrument called the McNaught, on which the pencil operates at right angles to the traverse of the piston, and where the revolving cylinder is detached from the body of the instrument. It will at once be seen that a tremulous or unsteady motion of the pencil on the revolving cylinder must impart a corresponding defect to the diagram, and is therefore calculated to lead to erroneous conclusions in the modes of valve setting—points of extreme nicety as to the actual condition of the Engine, or the minute alterations of its working parts which may be required to secure the greatest effect with the least expenditure of power.

In several other particulars Messrs. HOPKINSON have improved the *Steam Engine Indicator* for practical use. The instruments of their manufacture are not flimsy in construction: and care is taken to have all the working parts true and accurately fitted, so as to produce true and steady motion, with the least possible friction. Messrs. HOPKINSON have no hesitation in asserting that in these particulars the instruments of their manufacture will commend

themselves, and that the practitioner will find the new arrangement both convenient and useful. The diagrams taken by the *Indicator* manufactured by the Messrs. HOPKINSON are much larger than those usually taken by the instrument as commonly constructed, while the vacuum side of the diagrams is never decreased, whatever the pressure of the steam. The inch is divided into tenths on the vacuum side, one-tenth representing 1lb. pressure per square inch. This scale also applies to the steam side, for low pressures, up to 25lbs. For high pressures up to 75lbs, the inch is divided into thirtieths, one-thirtieth part of an inch representing 1lb. pressure. From this arrangement, the diagrams are much more readily divided and "read off," and the defects in the working of the Engine more clearly shewn, than by the ordinary mode. Experience has shewn that the working cylinder of the *Indicator* should be drawn out of brass tubing. By this method it is much truer and harder, and, if the piston be well ground in, the working of the instrument will be more accurate, and assist the operator in setting his valves with greater precision: advantages which cannot fail to be appreciated by those for whose use and benefit the instrument has been designed and improved.

ADVANTAGES OF

THE STEAM ENGINE INDICATOR.

With the *Steam Engine Indicator* a person may, at any time when his Engine is in motion, ascertain the working condition of that Engine—find out its defects—measure the power it is exerting—ascertain the difference of the pressure of steam upon the piston and within the boiler—and, at every part of the upward or downward stroke, know the exact pressure of the steam upon the piston at its various distances from the bottom to the top, and from the top to the bottom: also ascertain the amount of *lead* the valve is working with, on the steam and exhaust sides. The *Indicator* thus enables the operator to calculate with accuracy the pressure of steam exerted on the average throughout the whole length of the stroke—and learn at what part of the cylinder the piston is when the valve opens or closes, and what quantity (if any) of expansion he is working with. At one glance of the diagram he will have the interior—the inner working—of his machine, laid open as it were to view; its good qualities and its defects registered on paper by the Engine itself: thus dispensing with that system of guess-work often resorted to by Engineers who pretend to know defects and derangements by the working and beating of the Engine: a kind of fortune telling which many proprietors of Steam Engines have had to pay dearly

for. Without the *Indicator* and some experience in its use, and without a proper knowledge of the diagram when taken, no man ought to be allowed to alter, or set-up a Steam Engine to work, or to take the management of its working; for it is otherwise impossible to know anything of the inner working of the Engine, excepting from mere conjecture The *Indicator* is of as much importance to the Engineer and the proprietor of an Engine as a mariner's compass is to the captain of a ship navigating the seas. WATT placed the greatest reliance upon this valuable instrument; and it is not too much to say that it contributed greatly to the success of his many improvements in the Steam Engine. In a condensing Engine, by means of the *Indicator* the vacuum can be minutely examined and its quality ascertained. The instrument will also shew the exact pressure and time of the steam upon the piston—the opening and closing of the exhaust—very important to the proper working of the Engine. It will enable the Engineer to find the exact quantity of condensing water required, according to the temperature and quantity of steam to be condensed. In fact, by judicious observation, through the instrumentality of the *Indicator* the working of an Engine may, in most cases, be improved, and the power increased, the quantity of fuel being at the same time decreased. By means of this instrument the proprietor of a mill may ascertain the whole of the power in operation, and the force required to overcome the friction of his Engine and machinery; or the power required for any single room, or any particular machine or number of machines. Thus, where power is "let off," he may with accuracy determine the value according to

the power required. He may also calculate how much more power the Engine will exert by the increase of pressure, or the different degrees of expansion, according to the construction of his Engine and the other circumstances of the case. An extended knowledge of this instrument, therefore, becomes of importance to all connected with the Steam Engine, whether as makers, owners, or managers: for by its means they may obtain a correct knowledge of the working condition of every description of Engine, and also ascertain how to increase the power of each to its extreme limit of capability, with the least expenditure of fuel.

In the pages which follow, a popular description of this important instrument will be aimed at, that explanation being accompanied with examples and diagrams, to illustrate the working of the Steam Engine. Rules and tables to calculate the diagrams will also be given. In those rules and tables Algebraic signs will be avoided as much as possible. Men who have to manage the Steam Engine are not always conversant with Algebra; and our object is to make the rules we give, plain and simple—such as can be understood even by the commonest apprehension. Those more conversant with figures can exercise their own method of calculating; and although they may, if they please, calculate fractional parts, in practice the simple rules will be found equally efficient.

DESCRIPTION OF

THE STEAM ENGINE INDICATOR,

AS MANUFACTURED BY MESSRS. HOPKINSON.

PLATE II. is an engraved representation of the *Indicator*, with the additions and improvements made by Messrs. HOPKINSON. The plug A, screws into the cylinder cover, or grease tap. The tap H, forms a communication between the cylinder of the *Indicator* and the cylinder of the Engine. There is a small hole in the side of the tap, which opens into the tap-plug; and when the tap is open to the cylinder of the Steam Engine and the *Indicator*, this small hole is closed by the plug being turned with its perfect side against the hole. When the tap is closed, the connection with the Engine cylinder is cut off. The small hole in the tap is then open through the plug to the cylinder of the *Indicator*, so that any steam remaining between the piston of the *Indicator* and the plug of the tap may escape into the atmosphere, and allow the pencil attached to the piston of the *Indicator* to settle down to the atmospheric line. The cylinder of the *Indicator* is fitted with a piston, the rod of which is shewn at R. This piston is accurately ground into the cylinder, thereby avoiding packing; and, when properly oiled and cleaned, it is steam-tight, [illegible] very high pressures, where perfect tightness [illegible] as any small portion of steam which

PLATE II
R
F
M
E
I
K
H
A
J. HOPKINSON & CO.
ENGINEERS
HUDDERSFIELD
AND MANCHESTER

may escape cannot affect the bulk of the pressure in the cylinder. From this construction, the piston works freely with little friction. The piston rod R is attached to the spiral spring S, within the tube or casing F, placed above the steam-cylinder of the instrument. This spring is so adjusted, that when the piston index is forced one-tenth of an inch above the atmospheric line 0, marked on the scale E, it represents 1lb pressure of steam. The pointer forced *upward* each tenth of an inch, up to 25 tenths, will represent as many lbs pressure to the square inch. In the same way, when the vacuum is formed in the Engine cylinder, the spring will be distended by the pressure of the atmosphere upon the upper side of the *Indicator* piston, and the piston will be forced *downward* as many tenths of an inch as the degree of rarity, or the quantity of steam extracted from the Engine cylinder in lbs per square inch below the pressure of the common atmosphere. Affixed to the casing there is the scale E with the atmospheric line 0, in the centre. The tenths below 0 to 15, indicate the vacuum; and above 0 to 25 tenths, the steam pressure above the atmospheric pressure. The pencil-holder G is attached to the piston rod R through an aperture cut in the casing F, to allow the pencil-holder to move up and down with the piston rod of the *Indicator*. The pencil can be screwed backward or forward to obtain the exact length required, and is adjusted by a spring to allow it to accommodate itself to any little inequalities there may be on the revolving cylinder or the paper. In all cases a soft and good pencil should be used. The less the pressure upon the paper, the less the resistance to the free action of the piston I is the

revolving cylinder outside the casing F. This cylinder revolves on its own axis. The paper on which the diagram is to be taken is fixed around this cylinder, and held in its place by the clip J. On the bottom of the cylinder there is a cord round the pulley R, which, after passing over the swivel pulley A, is then attached to the radius-bar of the Engine. It will be obvious that the traverse of the radius bar will pull the cylinder so far round as the string thus travels. On the relaxation of the string, caused by the descent of the Engine piston, the pulley will again take up the cord, because an internal spring, similar to the spring of a self winding up measuring tape, is enclosed in the revolving cylinder. The traverse of the radius bar pulls the cylinder one way round, and the spring the other. By means of the cord attached to the radius bar of the Engine, there is thus produced a regular traversing motion of the cylinder I; and as the pencil presses at the same time against the paper affixed to the cylinder, and also moves up and down with the *Indicator* piston, which piston is propelled by the same force as the Engine piston, the pencil will describe a diagram according to the circumstances. The area of the cylinder of the *Indicator* is a quarter of a square inch; and each tenth of an inch on the index represents 1lb. pressure to the square inch on the piston of the Engine. The spring S, compressed, shews the steam pressure; distended, it shews the atmospheric pressure upon the piston of the *Indicator* caused by the formation of the vacuum in the Engine cylinder, varying in accordance with the pressure of the uncondensed steam left in the cylinder. This spring is so adjusted as to meet the requirements of the pressure as it

increases. When the steam exceeds 25lbs to the square inch above the pressure of the atmosphere, there is an additional spring enclosed in a case for higher pressures up to 75lbs to the square inch—or for a still further increased pressure if required—which is to be screwed on to the top of the casing F. This additional spring is represented at M. The piston rod of the *Indicator* passes up the centre of the spring M, when it is fixed on the top of the casing F, and comes in contact with the top attached to the second spring—so that instead of the resistance of only one, there is the resistance of two springs for high pressure steam. On the scale E, for high pressure, the distances are marked thirty to the inch, for steam above 25lbs; one thirtieth of an inch representing 1lb pressure to the square inch on the steam side. The scale on the vacuum side is ten to the inch; or one tenth of an inch represents 1lb pressure to the square inch, whether with high or low pressure steam. It should be borne in mind that whatever may be the pressure of the steam, high or low, when the Engine is a non-condensing or high-pressure Engine, the vacuum side of the *Indicator* is not required.

Means must be adopted to get the proper extent of traverse of the cylinder I. If the Engine be of the Horizontal or Cross-head kind, sometimes a lever is affixed to the cross-head of the piston, and the string from the *Indicator* attached to that lever at the requisite distance for the traverse required. Sometimes a stand with a moveable pulley is fixed to the Engine cylinder-cover by one of the bolts, to carry the string from the radius bar of the Engine to any part of the cylinder where the *Indicator* may be fixed.

With a Beam Engine, however, the *Indicator* is best fixed under the radius bar into a proper tap made for the purpose, screwed into the cover, or the bottom, of the Engine cylinder, where it can remain as a fixture ready for use at any time. For Locomotive Engines another and larger pulley may be attached, the circumference of which should be equal to the length of the stroke of the piston. The string may in that case be fixed direct to the cross-head or slide of the piston rod. The large pulley on the barrel of the *Indicator* will give out a sufficient length of string for one stroke of the Engine.

For Engines working at higher pressures than 75lbs, say as high as 250lbs per square inch, the *Indicator* is provided with another spring similar to the 75lb spring, and attached to the instrument in the same manner. Each case enclosing the spring to be used has marked on the outside the amount of pressure the spring will work up to. The measuring scale accompanying the *Indicator* is also so marked, that any figure taken by any of the three springs can be measured by it; thus dispensing with more than one portable scale. The 25lb spring is at all times a fixture, enclosed in the barrel of the instrument. The other springs require to be attached to the provision made at the uppermost part of the instrument for them.

HOW TO

AFFIX AND USE THE INDICATOR.

Be particular before using the *Indicator* that the parts are well *cleaned*—that the piston of the instrument vibrates freely in the cylinder—and that all the working parts are carefully oiled with clean sperm oil. If the instrument be new, let it be worked a few days on the Engine, and be well oiled and cleaned three or four times each day. To affix it, first screw the plug of the *Indicator* into the grease-tap, or into a tap in the cylinder cover provided for the purpose: or to the bottom of the cylinder, into a tap there inserted. The *Indicator* will work horizontally as well as perpendicularly. When the plug or tap is thus fixed, open the tap, and blow the steam through, so that any dirt which may have accumulated may be blown away, instead of being sent into the cylinder of the instrument. Then screw the *Indicator* on to the plug, or tap. Take one end of the string which is wound round the groove of the pulley on the bottom of the revolving cylinder, and connect it with a string on the radius bar of the Engine, if it be a Beam Engine. If a Marine Engine, or Cross-head Engine, attach to some convenient part which will give the string the requisite traversing motion, which must be from the direct action of the stroke, or the piston's traverse. The string must be so adjusted as to pull round the cylinder of the *Indicator* only

about three-fourths of a revolution. There is a stop or catch to prevent the cylinder being pulled round too far. On the string to be attached to the radius bar, there is a small brass plate, called a running loop. By pulling this loop backward or forward, the proper length of the string may be easily obtained, without detaching either from the Engine or the *Indicator*. When the strings are properly adjusted, unhook them, and open the tap between the cylinder of the Engine and the cylinder of the *Indicator* to allow the *Indicator*-piston to be worked a few strokes, so that the temperature of the cylinder of the instrument may be raised to that of the Engine cylinder. Then affix the paper round the moveable cylinder. When the paper is properly affixed, close the tap previously opened. The piston of the *Indicator* will then settle with the index or pointer opposite the atmospheric line 0. Put down the pencil upon the paper, taking care that the pencil does not press too much on the paper fixed on the cylinder. By means of the adjusting screw of the pencil-holder, the required amount of pressure upon the paper can be obtained to trace the diagram. When all else is ready, connect the two strings together by the hooks on each end. The traverse of the string attached to the radius bar of the Engine will pull the revolving cylinder as far round as has been arranged for; and its own internal spring will cause it to recede back again with the return stroke of the Engine. During these motions, the pencil will make a line on the paper round the cylinder. This line is called the atmospheric line. When that line is well defined, open the tap gently, so as to make a connection between the cylinder of the Engine and the cylinder of the *Indicator*. The piston

of the *Indicator* will then partake of the motion, and travel up and down with the piston of the Steam Engine, each stroke of the *Indicator* being exactly that of the stroke of the Engine, both being propelled by the same force. By these motions a diagram will be traced on the paper of the revolving cylinder by the pencil. Then shut the tap and disconnect the cord. Take off the paper, and the diagram will be found delineated thereon. By the aid of the scale sent with the *Indicator*, or the one affixed to the instrument, or by means of a common rule, the distances on the diagram from the atmospheric line on the steam side can be measured, which will give the exact pressure of steam per square inch upon the piston of the Engine. Pursue the same means with the vacuum side of the diagram; and the amount of vacuum obtained, and also the quantity of uncondensed steam left in the cylinder, will be ascertained.

Thus, every change and every deviation of the Engine will be exhibited, including those of expansion, lead, traverse of the valve, and closing of the exhaust. Expansion produces to all appearance, an irregular or defective diagram, (see diagram No. 2); but this is not the case, because the diminished pressure of the steam at the end of the stroke, or at the termination of the piston's descent, is much below the pressure of the atmosphere, thereby reducing the steam to a low degree, which is more than compensated by the saving of fuel. A very little lead of the valve is required, if the pressure be high. A diagram with the steam corner rounded, shews the valve to have little or no lead, the steam being admitted upon the piston easily. A diagram square and pointed, shews the valve to have too much lead,—that it opens too

quickly, admitting the steam upon the piston with too great a force before the crank is in a proper position to receive it. This will, in most cases, cause the Engine to tremble, and, by consequence, the *Indicator* also. Too much rounded at the commencement of the exhaust corner, shews also a defect for want of lead, or a quicker opening of the valve, or longer traverse of the valve on the exhaust side. In a great many instances the steam passages are too small. When that is the case the exhaust valve ought to be fully open when the crank is at the plumb centre. If the diagram be square at the termination of the exhaust, the valve closes too late. It would be better for the Engine were the valve to close sooner, more particularly if the speed of the Engine be great. Then the diagram would shew a rounding at the bottom corner, (see diagram No. 2.) This is important for the steady working of the Engine—preventing, in many instances, a rapping noise in the centres, which is often mistaken for loose cotters, or steps. The closing of the exhaust before the termination of the stroke, is called cushioning the piston. This will have to be regulated according to the speed of the Engine. The exhaust should be closed when the piston has to travel one tenth the length of the entire stroke. The piston and most of the working parts of an Engine having to be reversed, require to be brought to a stand before the return stroke. The steam left in the cylinder will be compressed, and check the speed of the piston at the end of the stroke. The elasticity of the compressed steam between the bottom or the top of the cylinder and the piston, is ready, by its force, to commence the return stroke with ease, preventing an undue strain

upon the Engine. The steam side of the valve does not require to be as forward as when the exhaust is open the full length of the stroke, because the compressed steam between the piston and the top or bottom of the cylinder, will act with a force according to its compression on the return stroke. For a very quick speed of the piston the opening on the steam side requires to be earlier, and as much steam admitted before the stroke is completed as will check the speed, and act as a cushion or buffer to the piston. If the valve be of the D kind, or if a tappit valve, it should be constructed so as to admit the steam on easy, before the valve opens full port. The Engine will in that case work much steadier—with less strain upon it. When the steam side of the valve has too much lead,—a serious defect, which will be hereafter noticed,—a rapping takes place. This is too often the result of imperfect valve-setting, and causes the *Indicator* to rebound by the suddenness of the pressure upon the piston, giving to the diagram an irregular line on the steam side. This irregularity is too often attributed to defection in the instrument, instead of the real cause, viz :—too much lead of the valve, and opening too quickly. In the working of an Engine, and in the taking of a diagram, care should be exercised to ascertain whether any defect of this kind exists, or an erroneous conclusion from the appearance of the diagram may be the result.

To enable the reader to understand more clearly the instructions above given, he is here presented with a diagram, showing the defects and advantages alluded to in the foregoing description. By attentively examining its form at the points marked, the reader will soon be able to comprehend the subject sufficiently

well to "read off" any diagram he may take from an Engine. Other examples will follow in their proper places: but at this point this is presented to render the instructions as to the use of the *Indicator* more intelligible.

Diagram No. 1.—Taken from the top of the cylinder of a Beam Engine. The steam corner A shews the valve at the commencement of the stroke to be rather too forward. It would be better were it a little later. Then the diagram would be a little rounded at the corner A, thus preventing the steam from pressing too much upon the piston when the crank is at the "plumb centre." The Engine is supposed to be working without expansion. The steam continues to the end of the stroke, as shewn at B, nearly at the same pressure the whole length, showing that the valve on the steam side has been open the full length of the stroke. The commencement of the exhaust corner C being rounded, shows that the valve is too late. It would be better had the exhaust more "lead"; that is, were the valve on the exhaust side to open a little sooner. This would allow the steam to escape into the condenser earlier, and give more power to the steam at the commencement of the stroke. The termination of the exhaust corner D being square, shews the valve also to be too late in closing the exhaust. If closed sooner, as before explained, the Engine would work much better. Should the valve be a D, or a common slide three port valve, add a little lap to the steam side, and set forward the valve by the eccentric. The valve in that case would not open full port. The exhaust would be opened sooner, and closed sooner, which is required. It would then shew a rounding at the corner D in pro-

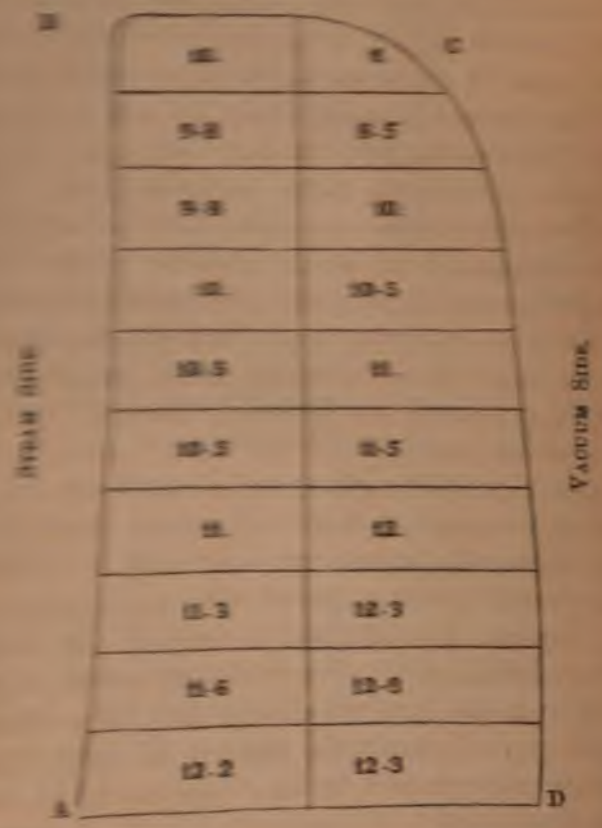
portion to the distance the valve had been moved forward. If the valves are of the kind known as the tappit, they can be regulated independently of each other, by the moving of the tappits.

The diagram being divided into ten equal parts, and each measured by the scale and figured as shewn, the average pressure of the steam above atmosphere, and the amount of vacuum, when added together, will shew the average pressure upon the piston at each stroke. The average pressure as shewn in the example is 21.31lbs per square inch upon the piston. The bottom or under side of the piston should be indicated, and the average of the top and bottom taken for the mean pressure per square inch throughout the stroke. This mode of measuring a diagram by dividing the length of the figure into ten parts, is the mode generally practised, and is found sufficiently correct for practical purposes. Where great exactness is required, a greater number of divisions can be resorted to, and the indication will thereby be the more exact, especially when the indication is from an Engine working steam expansively.

In measuring a diagram to ascertain the horse-power exerted, it will suffice to measure the steam side and vacuum side together, and to figure the indication accordingly. This rule will apply in all cases except when the high pressure spring is required to be used. In the latter case it is absolutely necessary to measure the steam and the vacuum sides separately, because the high pressure scale is thirty to the inch, and the vacuum scale only ten to the inch.

Diagram No. 1.

TAKEN FROM A SINGLE ENGINE WITH D VALVES WITHOUT LAP, FROM THE TOP OF THE CYLINDER.



Pressure of Steam 10.67lbs above Atmosphere.

10.64lbs vacuum.
10.67lbs pressure of Steam.
21.31lbs average pressure of Steam upon the Piston.

WHAT IS THE

VACUUM OF A STEAM ENGINE?

It is essential that we define and understand the term "VACUUM," as commonly applied to the Steam Engine, (and unless this be well understood by the Engineer he cannot clearly understand the Condensing Engine,) before we enter upon a description of the diagrams which are hereafter given. The following popular explanation is therefore attempted.

Steam is an invisible fluid. When steam, as it is called, is seen like white smoke, it is not steam, but minute particles of water. Pure steam in a glass does not shew at all, but the vessel appears to be filled with air only. One cubic inch of water converted into steam at the atmospheric pressure of 15lbs, the temperature 212°, will expand to 1700 cubic inches of steam. If the temperature be increased, the pressure will be increased also in the ratio of the temperature. Thus with steam at 251 degrees, the pressure will be 15lbs above atmospheric pressure; the total pressure 30lbs to the square inch, and the bulk 883 times greater than the bulk of the water from which the steam was produced. If the total pressure be 60lbs, or 45lbs on the steam guage, the bulk will be 470 times greater than the water the steam had been produced from. In proportion to the increase of pressure, so is the density.*

* See the Table at the end of this work, showing "the Temperature of Steam at different pressures."

The literal meaning of the term "vacuum" is space unoccupied by matter. The cylinder of a Steam Engine filled with steam vaporised from a small quantity of water, cannot be said to be void of matter; but condense that steam to its original bulk into water, and withdraw this water from the cylinder, and the space formerly occupied by the steam will be unoccupied. No matter remaining in the cylinder, there is what is termed a "vacuum," or a void space. We have supposed this operation to have taken place under the piston of a Steam Engine, and in that case there is no resistance to be overcome in the descent of the piston. The pressure of the atmosphere alone, which is 15lbs to the square inch, or thereabouts, would suffice to force the piston down with a power equal to the degree of vacuum formed, up to the limit stated—15lbs, if the vacuum be perfect. On this principle, the first Steam and Atmospheric Engine was constructed; a cylinder with its upper end open to the atmosphere; steam was admitted below the piston to raise it, and this steam being condensed in the cylinder itself, by the application of cold water, the pressure of the atmosphere alone caused the downward stroke, in the manner above described. If steam be allowed to take the place of the atmosphere, as in WATT's Engine, steam at atmospheric pressure will produce the same effect. 1700 cubic inches of steam, or one cubic inch of water converted into steam at atmospheric pressure, will have a force sufficient to raise a weight of one ton one foot high; two cubic inches of water, two tons; and each ton extra one additional inch of water, converted into steam. One of WATT's first improvements was, to attach to the Steam Engine a second

vessel in which to condense the steam. This he called a "condenser." He also introduced other alterations by which the vacuum was much improved, and the steam made to answer two purposes. First, by closing the cylinder with a cover, and admitting the steam between the cover and the piston, and connecting each side of the piston with the second vessel or condenser: the condenser being supplied with cold water, the steam was admitted at the same time by valves opening and closing at each stroke of the Engine; the steam was thus condensed, and a partial vacuum formed: and thus the power of steam at a pressure above the atmosphere was made available, in addition to the pressure of steam below the atmosphere. By admitting the steam alternately on each side of the piston, after a partial vacuum had been formed in the second vessel, or condenser, and the Engine cylinder, the Engine was thereby made to be double acting, and its power increased in proportion to the pressure of the steam above the pressure of the atmosphere.

Steam arising from an open vessel—for instance from the man-hole of a steam boiler—has a force greater than the pressure of the atmosphere, inasmuch as it has to displace the atmosphere before it can rise above the surface of the water. The resistance of the atmosphere is equal to about 15lbs on the square inch. It varies from 13½lbs to upwards of 15lbs; on the average it is about 14¾lbs to the square inch. 2.037 inches of a column of mercury balances 1lb pressure to the square inch. Therefore, steam enclosed in a steam boiler at 5lbs pressure per square inch above the atmosphere, or in other words, at 5lbs on the steam guage, is, in reality, a pressure of 20lbs on the

square inch, as applied to the piston of a Steam Engine under the conditions above stated, taking the pressure of the atmosphere at 15lbs. If the pressure be less, as it often is, say 14lbs, then the pressure upon the piston would be 19lbs, because the resistance of the atmosphere on the safety-valve and steam-gauge would be less, and the steam in the boiler also less, in proportion to the reduced pressure of the atmosphere. Hence it arises that an Engine heavily loaded varies in its speed with the varying pressure of the atmosphere. Suppose that the vacuum is not perfect—and in practice it never is so—and that there remains in the cylinder a portion of uncondensed steam the resistance of which is equal to 3lbs to the square inch, then the steam on the upper side of the piston at 5lbs to the square inch above the pressure of the atmosphere, would act with an effective force of 17lbs upon the square inch: the upper side of the piston having exerted upon it a pressure equal to 20lbs to the square inch, and the under side a pressure or resistance equal to 3lbs to the square inch. Under these circumstances, the condenser will have exhausted steam from the cylinder equal to 12lbs to the square inch, commonly termed a 12lbs vacuum; and uncondensed steam will have been left in the cylinder, having a resisting force equal to 3lbs to the square inch. In proportion to the quantity of steam condensed to the whole, so is the value or available pressure upon the piston. If the uncondensed steam left in the cylinder was equal to 6lbs to the square inch, then, as in the other circumstances supposed, the available pressure upon the piston would be only 14lbs to the square inch; a proof that vacuum is not power, as many are led to

suppose. All power in the Steam Engine is derived from the pressure of the steam upon the piston. If there be no resistance on the other side of the piston, the whole pressure is available; when there is resistance, whatever be the amount, it has to be deducted. The available power of steam on the piston is what is left of the whole force when that deduction is made. The term "suction" is often used. There is no such process in nature, or in mechanics, and the use of the term only tends to confound the practical worker. All power derived from air, steam, or gas, is the result of pressure, or density; and in proportion to the pressure so is the power.

If 5lbs more pressure to the square inch be added to the 5lbs before described, the pressure of the steam above the atmosphere will be 10lbs to the square inch, making only 25lbs as the available pressure. Many suppose that by doubling the pressure above the atmosphere, or double the pressure on the steam guage, they double the power of the steam, and that they also double the power of the Engine. Such is not the case. They have only, in the case last supposed—though the pressure of steam in the boiler above the atmosphere is doubled—added 5lbs to the 20lbs already available. This only gives 25lbs to the square inch upon the piston of the Engine in place of 20lbs. The increased power of the Engine is as 25 is to 20, supposing the non-resistance, or in other words, the vacuum, to be the same. In the practical working of Engines, it is seldom that the full pressure in the boiler can be brought upon the piston. To ascertain the real pressure operating on the piston at any given time, the *Indicator* has to be resorted to.

These examples have reference only to Condensing Engines. High-pressure or non-condensing Engines are constructed upon a different principle. In them, the power of the Engine is as the pressure of the steam above atmospheric pressure. Steam at 30lbs to the square inch above the atmosphere, that is 30lbs on the steam gauge, applied to the piston of a High-pressure or Non-condensing Engine, will exert a force equal to the pressure in the boiler above the atmosphere, providing there be sufficient room in the passages between the cylinder and the boiler, so that obstructions in the steam course do not reduce the pressure before entering the cylinder—the other side of the piston being open to the atmosphere, and the steam only having to overcome the atmospheric pressure in its escape from the cylinder. 15lbs from the total pressure of 45lbs is lost, provided the steam has been expanded in the cylinder to its full limit, which is not often the case in practice. If not expanded, the loss will be greater; it will be in proportion to the pressure of the steam on the piston above the atmosphere at the termination of the stroke. If we double the pressure in the case just supposed, and bring the whole pressure to bear upon the piston, and expand the steam to atmospheric pressure, the power of the Engine will not be doubled, but will be as 52 is to 31, because the pressure of the atmosphere added to 60 makes 75, not twice 45, which would be 90. Where a partial vacuum is formed, as in the Condensing Engine, steam at 30lbs to the square inch above the atmospheric pressure, would press with a force equal to 42lbs per square inch, supposing the resistance of the uncondensed steam to be only equal to 3lbs to the square inch.

As before observed, the one side of a piston of a High-pressure Engine is open to the atmosphere through the exhaust pipe, when the steam is exerting its force on the other side; and as the resistance of the atmosphere is 15lbs to the square inch, it follows that the power of the steam is as its own pressure above the atmosphere: or in other words, the pressure above the atmosphere is the available power obtained in the High-pressure or Non-condensing Engine, when the full pressure in the boiler is brought upon the piston.

The steam upon the piston of some Condensing Engines, is, at one portion of its stroke, below the atmospheric pressure, as may be seen by the diagrams: for instance diagram No. 2. The pressure of the steam upon the piston at the commencement of the stroke or descent of the piston, is for one-seventh the length of the cylinder, equal to 32lbs to the square inch, or 17lbs to the square inch above the pressure of the atmosphere. The valve is then closed and the communication with the boiler cut off, and the steam in the cylinder is expanded for the remainder of the stroke, decreasing as the piston approaches nearer and nearer to the end of the cylinder. Suppose the grease tap in the cylinder to remain open during the whole length of the stroke, the steam will rush out in proportion to its own pressure above the atmosphere, until the pressure is equalised. As the piston descends, the pressure of steam is reduced, by expansion, until it gets below the pressure of the atmosphere; and then the atmosphere will rush into the cylinder. At the same time the cylinder will be full of steam; (see diagram No. 2, where the steam is reduced to atmospheric pressure

when the piston is at the middle of the cylinder, crossing the atmospheric line). After crossing the atmospheric line, the steam is not equal to the resistance, or the power of the surrounding medium; therefore, at one portion of the descent of the piston the steam will rush out, displacing the air for a certain distance of the stroke from the top of the cylinder; and at the other portion of the stroke, or of the piston's descent, the air will rush into the cylinder, when the steam is below the pressure of the atmosphere, and will exert a force upon the piston equal to the difference in pressure between the steam and the air, because the pressure of the steam in the cylinder has been reduced by expansion below the pressure of the atmosphere; but when steam below the pressure of the atmosphere is admitted into the cylinder at the commencement of the stroke (see friction diagram No. 3,) the air will rush into the cylinder at the time the steam from the boiler is admitted, if the grease-tap be kept open from the commencement of the stroke to the end; thus showing the Engine to be working with steam at a less pressure than steam from an open vessel; or in other words, steam below the pressure of the atmosphere. Were the openings sufficiently large to admit a sufficient quantity of air, no steam could enter the cylinder against the superior pressure of the atmosphere. If the steam in the boiler were below the pressure of the atmosphere, the boiler would soon be filled with air.

When steam at a pressure above the atmosphere is admitted into the cylinder (see diagram No. 1,) and kept up to the end of the stroke, the steam would rush out of the grease-tap, were it open the whole length of the stroke, because the steam in the

cylinder has not been reduced by expansion, but has to be condensed in the condenser by an extra quantity of water; thus giving the air-pump more work to do, and losing a quantity of steam in proportion to the pressure. If the steam be reduced to the lowest practical working pressure by expansion, the most has been made of it; but if not expanded to its full limit, the loss will be in proportion to the amount of pressure left in the cylinder previous to condensation—or the exhaustion into the atmosphere, if a High-pressure Engine.

In a Steam Engine not heavily loaded, working with steam below the pressure of the atmosphere from the boiler and in the cylinder, as in diagram No. 3, were the safety valve lifted from its seat, air would rush into the boiler, until the pressure became equal to the pressure of the atmosphere. Thus air and steam would rush into the cylinder of the Engine with a force equal to the pressure of the atmosphere. As air cannot be condensed, like steam, the vacuum would be destroyed, and there would consequently be an equal pressure on each side of the piston. The result would be a stoppage of the Engine.

NOMINAL AND INDICATED

HORSE POWER OF STEAM ENGINES.

THE nominal horse power of a Steam Engine, as laid down by JAMES WATT, the inventor of the *Steam Engine Indicator*, is 33,000lbs raised one foot high per minute, or any less weight a proportionately greater height in the same space of time. Upon this calculation he defined the power exerted. His first premise was to ascertain the average pressure of steam upon the piston; and for this, as a standard, he laid down, as a rule, an available pressure of 7lbs per square inch. The speed of the piston he computed at 220 feet per minute. These in his day were about the average pressure and speed Steam Engines worked at. Thus a Steam Engine with a cylinder twenty-six inches diameter, with an average pressure of steam and vacuum* on the piston of 7lbs per square inch—when the friction of the Engine is deducted—travelling two hundred and twenty feet per minute, will be of twenty-four horse power, or, as it is termed, a twenty-four horse Engine. It would in fact, be no more, when worked at the before named pressure and speed; that is, it could exert no more than twenty-four horse power. This then is, nominally, a twenty-four horse Engine; and were the *Indicator* to be applied, it would show the Engine to be working not more than twenty-four

* This term is here used as in general parlance: not that there is POWER in vacuum; but to make the rule understood amongst those who use the term, the popular idea is here adopted.

available horse power; for the "indicated" horse power in this case would be *precisely* the same as the "nominal"; viz., 33,000lbs raised one foot high per minute.

The term "*nominal* horse power" is used, because we ascertain originally the power of an Engine by calculation on the basis above laid down; and when we say "*indicated* horse power," it is because we ascertain the power by means of the instrument known as the *Indicator*. A horse power, whether termed "nominal" or "indicated," is therefore nothing more nor less than 33,000lbs raised to the height before described—independently of the friction of the Engine.

But let us supose the same Engine to be worked at an increased pressure—say at 30lbs per square inch average steam and vacuum; and the speed, instead of being two hundred and twenty, to be increased to three hundred and fifty feet per minute—(and many Engines are worked at the speed and pressure here referred to)—the power of the Engine would be increased to one hundred and sixty-eight horse power—or to seven times the amount of the "nominal" designation. Though still "nominally" a twenty-four horse Engine, it would, in reality, be an Engine of one hundred and sixty-eight horse power. At the speed and pressure above stated, it would indicate that amount. Thus it is by the increase of speed and pressure that Steam Engines are made to exert more power than they were originally calculated for; or, at least, more power than the "nominal" designation. Steam Engines are now made much stronger for the same nominal power, than in the days of WATT. With all Steam

Engines, as the pressure and speed are increased, so is the power increased; but this augmentation of power is not obtained without an increased quantity of steam proportionate to the increased pressure, except where steam is used expansively. It will therefore be apparent that the term "nominal" horse power can only be *legitimately* used in the sale or *purchase* of an Engine. On this rule a twenty-four horse Engine means that the cylinder shall be twenty-six inches diameter, if a Condensing Engine; and in the same proportion for a larger or a smaller Engine; for twenty-two square inches of area of the piston is one "nominal" horse, if a Condensing Engine. If we multiply the diameter of the cylinder by the diameter, and divide by twenty-eight, the product will be the number of "nominal" horse power. The purchaser of a Condensing Engine should have twenty-two square inches area of piston for each "nominal" horse power, whatever the speed or pressure. The *real* power exerted can only be ascertained by the *Indicator;* hence the term "indicated horse power."

This is the standard mode of ascertaining the real power for Condensing Engines, as laid down and established by WATT. It is now universally followed by Engineers. In a case tried at Westminster, where power had been "let by the horse," it was referred to arbitration; and the question arose "what constitutes a horse power?" After due enquiry, it was legally established, for the first time, that 33,000lbs raised one foot high per minute is one horse power, which in the Steam Engine can only be correctly ascertained by the use of the *Indicator*.

The term "commercial horse power," has lately

been used by some parties; and they say one "commercial" horse power is equal to three "indicated" horse power. The substitution of the term "commercial horse power" for "nominal horse power," would appear to be a change without a principle, calculated to lead to endless disputes in the purchase of Engines; because it does not define the diameter of the cylinder, as by the present rule; and it could in no way, that we can see, be advantageous. The rule laid down by WATT is correct in principle, and is so plain and so easy to understand that no change is required.

Non-condensing, or High pressure Engines, are calculated for the "nominal" power by the following rule: Eleven square inches area of piston is one "nominal" horse power. Multiply the diameter of the cylinder by the diameter, and divide by fourteen, the quotient will be the number of nominal horse power.

A High-pressure Engine, working with 40lbs steam above atmosphere upon the piston, cut off at one third the length of the cylinder, and expanding the remainder, the piston travelling 220 feet per minute, would only exert the power for which it was "nominally" calculated, independent of friction; but take the same Engine and increase the speed from 220 to 440 feet per minute,—which is quite practicable in a Horizontal Engine, if the fly-wheel be not too large,—the power of that Engine would then be doubled, less the extra friction; but double the quantity of steam would have been used. The exhaust steam would be thrown away at the termination of the stroke at 3½lbs above the pressure of the atmosphere. Suppose steam were introduced to the same

cylinder at 80lbs pressure, and cut off at one third, and worked expansively, as in the first case, the exhaust steam would be thrown away at 16½lbs above the pressure of the atmosphere, being five and a half times the pressure, or loss, sustained from steam at 40lbs. The power given out would also be less in proportion. Steam at 40lbs would yield thirty-eight and a half horse power, whilst steam at 80lbs, and cut off at the same point, would only yield sixty-six and a half, thus showing that the steam has not been used up. A portion of it is lost, in consequence of not being expanded to its full limit, the lost portion escaping into the atmosphere, exerting a corresponding back pressure upon the piston.

High-pressure Engines work at such varied pressures and speeds, that the *real* power can only be ascertained by the *Indicator;* but the "nominal" power can be calculated by the rules before explained. In the purchase of a High-pressure Engine, the buyer should have eleven square inches area of piston for each "nominal" horse power, whatever may be the speed or the pressure the Engine can be worked at. One cubic foot of water evaporated per hour is taken to be one "nominal" horse power, or 1,728 cubic feet of steam, at atmospheric pressure: the quantity of steam one cubic foot of water would expand to, at the pressure before named. The use of High-pressure Engines having become general,—being now applied almost to every purpose,—the author will, in another chapter, enter more fully into explanation—prompted by experience that this class of Engine and its proper working are either misunderstood, or that little attention is devoted to construct them so as to work economically. As they are now so generally adopted,

he cannot but infer that the former is the fact—otherwise there is great disinclination on the part of the Engineering profession to depart from what may be designated a beaten track.

EXPANSION OF STEAM.

Expansion of steam takes place when the communication with the boiler is cut off from the cylinder of the Engine, after the piston has travelled a portion of its stroke. The steam thus enclosed betwixt the piston and top (or bottom) of the cylinder, forces the piston forward to the end of the stroke. Supposing the valve to have closed when the piston had travelled one-fourth the length of the cylinder, and its pressure at that time to be 20lbs above atmosphere on each square inch, or 35lbs the total pressure per square inch upon the piston, it would begin to decrease in pressure as the piston were forced forward, till the piston reached the end of the stroke, when the pressure would be 8¾lbs per square inch. For one-fourth the length of the cylinder, the pressure would be 35lbs per square inch; that is, while the communication between the boiler and the face of the piston remained open. This communication being closed at that point, the steam would begin to expand, forcing the piston forward. When the latter arrived at half stroke, or at the half length of the cylinder, the pressure would be 17½lbs upon the square inch. When the piston arrived at three-fourths the length of the cylinder, the pressure upon the piston would be 12¾lbs per square inch; and at the end of the stroke the pressure upon the piston would be 8¾lbs per square inch, or 6¼lbs per square inch below the pressure of the atmosphere—the steam having gradually expanded during the traverse of the piston, from 35lbs at the

commencement and up to one-fourth of that traverse, down to $8\frac{3}{4}$lbs at the termination of the stroke, leaving only the latter amount of steam to be condensed.

Expansion is, perhaps, the most extrordinary property of steam. Many Engineers have pursued their enquiries on this subject with great accuracy by the aid of the *Indicator*, and they have thereby been enabled to obtain great advantages by reducing the consumption of fuel for the same amount of power obtained, within perfectly safe limits. The merit of the discovery is due to HORNBLOWER, who, in 1781, obtained a patent for the invention. He states that when steam is confined on one side of a piston, and a partial vacuum is formed on the other, the steam will move the piston till its force is in equilibrium with the friction and uncondensed steam on the under side of the piston, and power is communicated during the motion, in addition to the ordinary effect of the original steam pressure. To apply this power, which was *lost* before, HORNBLOWER used two cylinders in which the steam was to act; employing the steam, after it had acted in the first cylinder, to operate a second time in the second and larger cylinder, by permitting it to expand. This he accomplished by connecting the cylinders together by proper apertures. We give his own description in the words of his specification:—" I employ the steam after it has acted in the first vessel to operate a second time on the other, by permitting it to expand itself, which I do by connecting the two vessels together."

The expansive property of steam is strictly mechanical, and is a property common to all fluids, air, gas, &c. It simply consists in this—that vapour of a given elastic force will expand to certain limits,

and during the process of expansion will act on opposing bodies with a force gradually decreasing, causing a diminution of elastic power in an inverse ratio to the increase of volume, until it has reached the limits of its power, or is counterbalanced by the resistance of a surrounding medium. Thus, steam of any given pressure, expanded to twice its original bulk, will exert only one half its original power. If a partial vacuum be formed on one side of a piston, its motion will be continued until the density of the steam on the other side be as low as that of the uncondensed vapour on the vacuum side of the piston. It is clear that the power which may be obtained by thus impelling a piston will be the average between the highest and the lowest pressure on the piston. It must also be well understood, that IT IS A SAVING, AND NOT A GAIN, that thus results from expansion: a power being made available which was before lost, by using the steam up to its last impelling force, and not allowing it to escape until the whole of that available force is expended. This accounts for some Engines using more fuel and steam than others, because the steam is not expanded to its utmost limit, in consequence of the steam not being cut off by the valve soon enough; or that the load on the Engine is great, and requires the steam to be longer on the piston before it is cut off. If the load on the Engine be such as to allow the steam to be cut off early, and to expand to its full available limits in the cylinder, then the most will have been made of it: the highest pressure on the boiler will have been used upon the piston, and down to the lowest point. Were atmospheric air compressed so as to exert a force of 20lbs on the square inch, and were the supply to be

continued throughout the stroke, an impulse would be given to the piston equal to 20lbs to the square inch during the whole stroke; but if the air was allowed to expand, the impulse would only be as the average, or 10lbs. It will be evident, that if in the former case the air was suffered to depart from the cylinder at the same elasticity as that which it entered, we should lose the force which was necessary to compress it to its density; while, by expanding it to its limits, we should apply every part of that force. The main spring of a watch actuates its machinery in this manner; an increasing effort is required to wind up the spring, and a decreasing impulse is given back to the machinery. But, if after the spring had partially uncoiled itself it were then liberated, the force which wound it up to its last impelling point would be totally lost. So in the Steam Engine: if the steam be allowed to escape from the cylinder before its force is expended, by expanding to the lowest available pressure, the loss will be in proportion to the amount of the pressure not made available.

A certain quantity of fuel is required to raise steam to a certain elasticity. If that steam be allowed, after having moved the piston, to escape into the atmosphere or condenser without having acted expansively (see diagram No. 1), a portion of the fuel which was consumed to raise the steam up to that point of elasticity will have been lost. In one case a given bulk of fuel would produce fifty: in the other case it would produce fifty, added to all the intermediates down to the lowest expansive force. For example: diagram No. 1 shows the steam on the piston the whole length of the stroke; and diagram No. 2, the

steam cut off at one-seventh the length of the stroke —the pressure of the steam decreasing as the piston advances the other six parts of the stroke. In No. 1, the steam escapes into the condenser at 25lbs pressure —10lbs to the square inch above atmosphere, and in No. 2, at 10lbs to the square inch—5lbs below the pressure of the atmosphere; shewing a loss in No. 1 of 15lbs out of the 25lbs as compared with No. 2. Had the steam in No. 1 been allowed to expand as in No. 2, less than one-half the steam would have given out the same amount of power.

By this it will be apparent that the advantages arising from expansion increase with the density of the steam. In round numbers, 65 of high-pressure steam performs more than seven times the duty of 25 of low-pressure steam: a fact greatly in favour of high-pressure steam and expansion. In Condensing Engines the steam expands to half an atmosphere, and sometimes below. In Non-condensing Engines the steam expands to one or two pounds above atmosphere, but often not so low. This entails a loss in proportion to the pressure of the steam thrown into the atmosphere.

In Cornwall the principle of expansion has been carried to a most profitable extent. A report made in 1788, of the work performed by seventeen Engines of WATT's construction, then working in Cornwall, shewed that their average duty was 19,569,000lbs of water raised one foot high with one bushel of coal 94lbs weight, which exceeded the performance of the former Atmospheric Engines, in the ratio of $2\frac{3}{4}$ to 1. Some years after, disputes having arisen as to the performance of WATT's Engines, the matter was referred to five gentlemen, of whom Mr. DAVIS

GILBERT was one; and in May, 1798, the arbiters made their award. The average of twenty-five Engines was 17,671,000lbs of water raised one foot high, with one bushel of coal. Since that period, so great have been the improvements resulting in the economy of fuel, that in December, 1829, the duty of the best Engines was 75,628,000lbs of water raised one foot, with one bushel of coal. Such was the effect of high pressure, and expanding the steam in one cylinder. In 1829, the working of steam by expansion had been still further improved; and experiments made by Mr. E. GALLOWAY, Civil Engineer, to test the capabilities of Mr. WILSON's Engine, at Wheal Towan, in Cornwall, gave as the result, 127,693,028lbs of water raised one foot high, with one bushel of coal. In 1841, other improvements of the expansive principle took place. Mr. SIMMS had an Engine constructed on HORNBLOWER's principle, with two cylinders, the one above the other—the top one being what is termed High-pressure, and both pistons attached to one rod. This Engine performed the enormous task of lifting 160,721,120lbs of water one foot high, with one bushel of coal 96lbs weight; under 1¼lbs per hour per horse power. Since 1841, further improvements, by the aid of higher pressures, have taken place, proving the advantage of high-pressure steam and expansion over that of low-pressure steam and no expansion.

The expansive principle propels our Locomotive Engines with economy and speed from place to place. The cost of fuel for Locomotive Engines, at the commencement of the Liverpool and Manchester Railway, to propel a ton of merchandise one mile, was above twopence: at the present time it is under one farthing

per ton per mile. The increased pressure of the steam, and allowing it to expand in the cylinder, has been the great means of reducing the cost of fuel on railways. We are enabled by the same principle to cross the Atlantic and the Pacific with steam vessels. The time is not far distant when the principle will be carried out much more extensively. In Marine Engines, the want of a boiler constructed on the true principles of greatest resistance is the only desideratum to extend the principle of high-pressure and expansion, and to derive, in the case of Marine Engines, similar advantages to those which have resulted in Stationary and Locomotive Engines. A great saving in room would result from the adoption of high-pressure steam, and a reduction of fuel to an incredible amount, with a less outlay as first cost. Sailing vessels might thus have auxiliary Steam Engines to be used at pleasure, and possess a means of greater safety and dispatch than have hitherto been accomplished with low-pressure steam and dangerous boilers of large dimensions.

High-pressure or Non-condensing Engines for steam ships could be made to work up the steam, by expansion, to the lowest possible limit, before parting with it, by using two cylinders,—the same as HORNBLOWER—the second cylinder being Non-condensing; or by a number of cylinders worked at different angles, so that the power of the steam could be exerted equally throughout the stroke.

Simple High-pressure Engines could thus work up to great speeds—very advantageous to screw propellers. They would not be so liable to derangement and breakdowns as the present Low-pressure Engines. In cases of danger, the pressure might be doubled, and the power of the Engine thereby

very much increased—an advantage which would be found most beneficial in storms.

Since former editions of this work appeared, Marine Engineers have begun to act on the principles recommended in the foregoing, and the results have been most satisfactory.

TO FIND THE POWER OF A STEAM ENGINE ON THE BASIS OF WATT'S DEFINITION.

DEFINITION.

As before explained, a HORSE POWER is that amount of moving force which, besides overcoming all friction, will raise 33,000lbs weight one foot high per minute: or any smaller weight a proportionately greater height in the same time.

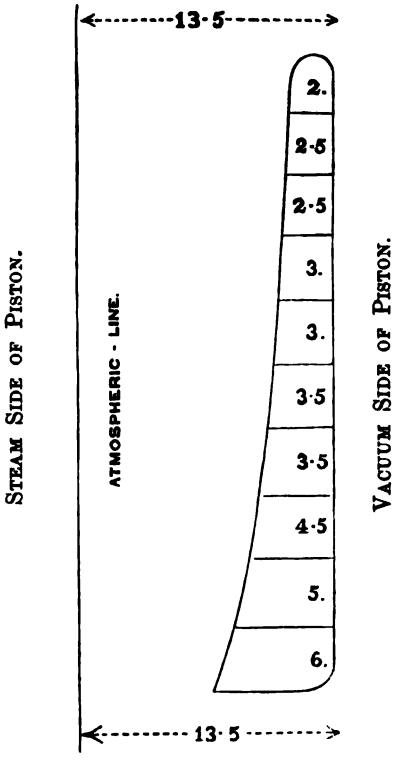
RULE.

By means of the *Indicator*, take off a friction diagram when the Engine has no machinery attached —only the shafting. Divide the length of the figure into ten equal parts. Measure across the centre of each division by the scale of the instrument, or with a common rule. When the number of pounds to the inch has been ascertained, write them down on each division of the diagram; then cast them up, and divide the product by ten. If the figure be divided into more than ten, the product must be divided by the number of the divisions on the diagram. The quotient will be the average pressure in pounds upon each square inch of the piston—(see diagrams Nos. 3 and 2). No. 3 is a friction diagram, and No. 2 a diagram with the Engine loaded with machinery. It may be mentioned that the average friction of Stationary Engines with the shafting, is

to the square inch, and of the Marine Engines
s to the square inch upon the Engine piston. If
iction diagram cannot be conveniently obtained,
above is the calculation generally adopted by
gineers, when the available power is required to be
wn; but where possible, it is best, for accuracy,
; a friction diagram should be taken. The
owing is an example:—

Friction Diagram No. 3.

Taken from the Top of a Condensing Engine Cylinder.



3·5lbs.

Average Pressure, 3·5lbs to the square inch upon the piston.

In this diagram, the steam in the cylinder is below the pressure of the atmosphere the full length of the stroke, the load usually on the Engine being detached, except for shafting.

EXPLANATION OF THE READING OF DIAGRAMS.

3·5 mean three pounds and a half upon the square inch. Ten being the whole number, five is half; and all figures from one to ten are in proportion. 2·5, with a dot between, mean two and a half pounds; 3·8 mean three and eight tenths of a pound; and so on with all figures below ten. 10·5 also mean ten and a half pounds to the square inch; so with other numbers; 21·6 mean twenty one pounds and six tenths of a pound.

The rule for calculating the diagrams from the *Indicator* is given in this simple way, that any person possessing only an indifferent knowledge of figures may understand that rule; for many who were disposed to learn the use of the *Indicator* have been deterred by the use of Algebraic signs in the figuring and calculating of diagrams. These signs are as Greek to a great number of "Engine-men," who have not had the benefit of a mathematical education. With the rule here laid down, the comparatively uneducated amongst them can have no difficulty, and the result, for all practical purposes, will be sufficiently accurate.

If the steam upon the piston be below the atmospheric line, the same as in No. 3 diagram, there will only be one column to add up; but if the steam on the cylinder be above atmospheric pressure, as in No. 2 diagram, there will be two columns to add up,

on the steam side, and one on the vacuum side; these two will have to be added together to get whole pressure. They may be measured at one asurement when the steam and the vacuum are on tenth scale, which is the case where the pressure under 25lbs upon the piston. In the case of a gh-pressure Engine, there will only be one column he steam side.

RULE TO ASCERTAIN THE POWER

REQUIRED TO DRIVE ANY QUANTITY OF

MACHINERY : OR THE POWER

THE ENGINE IS EXERTING.

WITH the *Indicator* take off a diagram when the load is on, or with the machinery in operation you wish to know the power it will take to drive. For example: diagram No. 2 is taken from a Condensing Engine with the whole of the machinery in motion, belonging to Mr. GOADSBY, of Manchester, that Engine being considered a good example of expanding steam in the cylinder, and also of the setting of valves.

RULE.

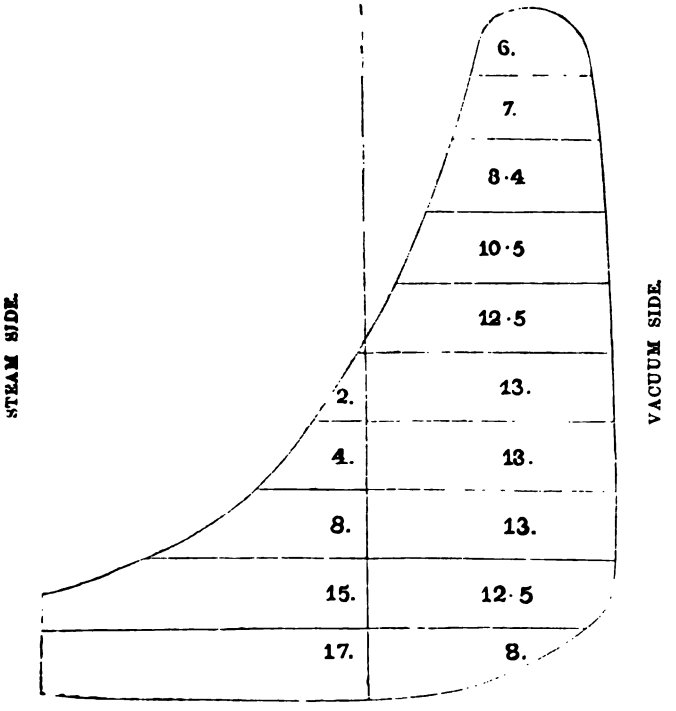
The area of the cylinder being given in square inches, multiply by the speed the piston travels in feet per minute, and multiply by the available average pressure in pounds per square inch upon the piston, having deducted the friction of the Engine and shafting, as below: the multiplicand will give the number of available horse power—independently of the friction of the Engine—when divided by 33,000lbs.

By giving the number of feet per minute traversed by the piston and the diameter of the cylinder, with a diagram, any person conversant with the use of the *Indicator* will be able at any time to ascertain the state of his Engine, and what amount of available power it is exerting, or the power for the whole of the

machinery the Engine is driving, including shafting and its own friction. It will not be necessary to send for any one to examine the Engine; the diagram will be quite sufficient to explain its condition. For example, examine

DIAGRAM No. 2,

Taken from the Top of a Condensing Cylinder.



4·6 steam. 10·4 vacuum.

10·4 vacuum.
4·6 steam.

Deduct friction diagram; or the power required for Engine and shafting ..... 15·0—the average pressure upon the piston.
3·0lbs

12·0lbs the available pressure upon each square inch of the piston.

Multiply twice the length of the stroke in feet by the number of revolutions per minute, the product will be the speed the piston travelled in feet per minute.

EXAMPLE:

Diameter of cylinder 32 inches;* speed of piston in feet, per minute, 340.

Multiply the cylinder's diameter by the diameter	32 32 — 64 96 ———	
To ascertain the number of square inches, multiply by	1024 ·7854 ——— 4096 5120 8192 7168 ———	which is the decimal area of a circle of one inch, 10,000 being 1 square inch.
	804·2496 340 ———	square inches of the piston. Multiply by speed of piston 340 feet per minute.
Multiply by the effective pressure upon the piston when the friction of the Engine and Shafting has been deducted -	321699840 24127488 ——— 273444·8640 12 ———	lbs the average available pressure.
Divide by 33000)	3281338·3680 297000 (99 ——— 311338 297000 ——— 14338 towards 33000.	take off four figures, being the decimal figures of 7854; and the dividend 99 is the number of horse-power.

By the rule given, we find that this Engine was exerting ninety-nine available horse-power, or one

* To save the trouble of squaring the diameter, see Table of Circumferences and Areas of Circles (in Appendix), which gives the areas of circles, per square inch, from one sixteenth of an inch to one hundred inches diameter; and from eight feet in inches to thirty feet in diameter. In this case, it will be found to be 804·2496 square inches, area.

hundred and nineteen horse, including friction of Engine and shafting. At the time the diagram was taken, it was consuming eleven tons of coal per week, including steam for mill, &c., with two boilers of FAIRBAIRN's patent oval double fire-box construction. Suppose the eleven tons to be consumed by the Engine when working sixty hours per week, what is the quantity of coal consumed per hour?

EXAMPLE:

```
Multiply the number of hours  60
    by the horse power ... ...  99
                              ----
                               540
                              540
                              ----
                              5940  hours and horse power together.
                              ----
Reduce the weekly consumption 2240lbs—1 ton.
    of tons into lbs  ... ...   11—the number of tons per week.
Divide by the horse-          ----
    power and the num- 5940)24640  4lbs 2oz. 5dr. the consumption
    ber of hours together   23760    per hour per horse power.
                            -----    If we deduct the steam for
Multiply by the number of oz.  880   heating the mill, this will re-
    in the pound ... ... ...    16oz. duce the consumption for the
                            -----    Engine under 4lbs per avail-
                             5280    able-horse power, or to 3lbs
                             880     per hour per horse, for the
Divide by the divisor as    -----    whole power exerted.
    before ... ... 5940) 14080 (2oz.
                         11880
                         -----
Multiply by the number of  2200
    drachms in the oz. ...   16 drachms 1 oz.
                           -----
                           13200
                           2200
                           -----
Divide by the divisor 5940)  35200 (5 drachms.
                             29700
                             -----
                              5500  towards 1 drachm.
```

This rate of consumption is under the average of Engines expanding the steam in the same cylinder at a pressure of 30lbs in the boiler, which is quite as much as this description of boiler should be worked at. The steam in this Engine having expanded to 6lbs below the pressure of the atmosphere, is better used up than in most cases. Where HORNBLOWER's principle is in operation, with high-pressure steam from 60lbs to 100lbs to the square inch—expanding that steam in a second cylinder; or where there is a separate High-pressure Engine—the steam first acting in the high-pressure cylinder, and then passing to the Condensing Engine (a construction common in Lancashire among cotton manufactories), the consumption of fuel is much less—from 3lbs to 3½lbs per available horse-power per hour. And in some instances, with improved boilers calculated to resist high-pressure with safety, and with good water, the consumption of fuel is still less. But where the consumption is thus small, every care is taken. The Engine is indicated every day, and the diagram put into a book for reference: so that should any alteration take place in the working of the Engine or the machinery, or even an increase of friction from bad oil or other causes, it is easily detected. It is found out before it is visible in the amount of fuel wasted; and instead of the fuel being lost, the defect is remedied. This is as it ought to be; and were the practice followed up in all cases with the same exactness as the time of starting and stopping the Engines, it would be productive of great advantage to owners, and save Engineers many a late hour now spent in the examination of Engines after the work of others has terminated. It is as necessary for an Engineer

to have the working interior of his Engine laid open before him in a diagram taken every day, as it is for him to see the exterior. Such a practice, if regularly attended to, would save many "break-downs" and expensive repairs, besides making the mind familiar with the internal working of the Engine. Any alteration in the working of his Engine would cause the Engineer to reason out the various changes that take place from day to day. The advantage would become so apparent, that he would continue to make improvements in the management and working of his Engine, to economise the fuel, and regulate the speed. These important benefits could all be attained with less labour than is entailed by the hap-hazard and guess-work system.

Were Engineers taught the principles of indicating, and the nature of the machine entrusted to their care, Inspectors of Steam Engines and boilers would not be required. These Inspectors are often more conversant with report-making than with the practical management of the Steam Engine or boiler. This system of extraneous inspection is retrogade in tendency. By its means responsibility is taken from the proper parties upon whom it should be devolved, and placed in the hands of an irresponsible body, managed according to official routine. Experience has proved that this course does not result in progress; for under it there is the want of practical information and competitive power to stimulate to progressive action. Many Steam Engine establishments do not possess an *Indicator*, but rely upon the Inspector, who may call once in three months with an instrument—one adopted by official power, small in construction, and not very sensitive.

To carry one larger would be too burdensome to the Inspector, although it is better calculated to give a diagram that could be properly read. Under such circumstances, the Engineer is left to grope his way, —a state of things that may be sustentative of officials, but it is not advantageous to the manufacturers or the proprietors of Steam Engines, and it certainly is detrimental to science.

If the amount of money expended in Lancashire and Yorkshire in the formation and sustentation of "Associations" to remove responsibility from where it ought to rest, had been expended in the scientific and practical instruction of the working Engineers of those two counties, the result would have been of a more valuable and permanent character: for the latent talent which often lies concealed in humble positions would then have had a chance of development. Such a course, at any rate, would have taught the working Engineers, as a body, to understand scientific principles as applicable to their art and calling; and also enabled them to understand in practice the motive power entrusted to their care. They would thereby have been enabled to understand the force and bearing of "Reports" emanating from any "Association," and practical science would thus have received a stimulus. Instead of this, however, the working Engineer has been considered to be only a machine to perform the functions prescribed by others, while the "Report"-maker has been elevated into the position of "official" dictator.

THE CONSTRUCTION AND ACTION OF VALVES.

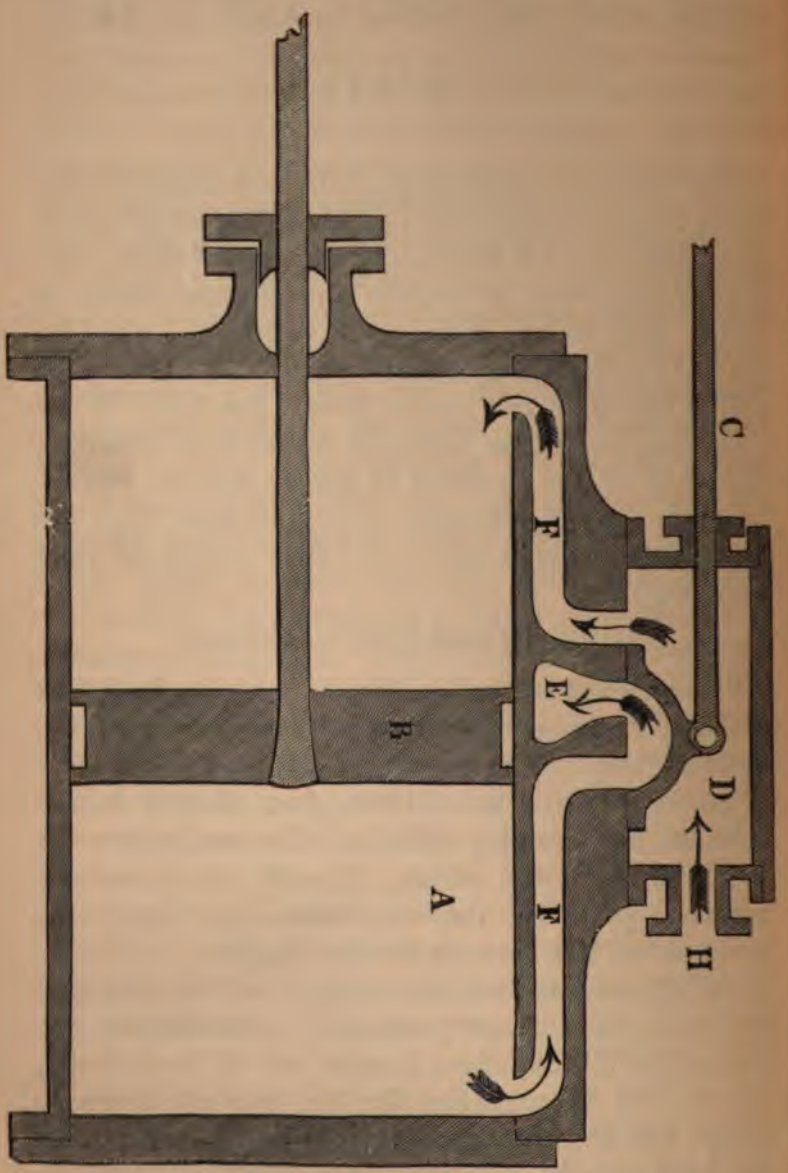
The reader, by this time, will have learned something respecting the form and the different points to be understood of a diagram. It has, therefore, now become necessary to explain the different forms of valves used in the working of steam in connection with the Steam Engine; and as these parts may be said to be, as in the human frame, the heart of the structure, should the heart be diseased or deranged, the whole of the structure or system will be thereby affected. How necessary is it, therefore, that the form and proper working of valves should be fully understood.

COMMON THREE PORT SLIDE-VALVE.

The annexed engraving, Fig. 4, is an illustration of a Steam Engine cylinder with a three port slide-valve, without "lap." The arrow at H denotes the admission of steam into the valve chest, from thence to the cylinder, and from the cylinder, after having exerted its force upon the piston, through the valve and exhaust port to the condenser—or into the atmosphere, if a Non-condensing Engine.

On reference to the illustration, it will be seen that the steam and exhaust ports are of equal dimensions; F F are the thoroughfares to each end of the cylinder, and E, the thoroughfare for the exhaust steam to escape into the condenser, or into the atmosphere, as the case may be.

FIGURE No. 4.



The valve, as now shewn, is attached to the rod C, the traverse being attained by means of an eccentric or other motion from another part of the Engine. When the Engine makes one-half of a revolution, or one stroke up or down, the valve changes its position accordingly.

As before observed, the arrow H denotes the steam passage from the boiler to the valve chest D. As the valve is shewn, there is a direct opening for the steam through the steam way F, to act upon the piston B; and on the under side A, through the exhaust way F, there is a free passage for the exhaust steam into the condenser, or atmosphere, as shewn at E. The valve being hollow on the under side, permits the egress, as shewn. It will be observed that the faces of the valve will little more than cover the ports, and this construction is therefore appropriately termed "without cover," or "lap."

Suppose then, that the piston had proceeded in its traverse to the end of the stroke, the valve would also have changed in position and action; the steam from the steam chest would be admitted at the other end of the valve on to the other side of the piston, and the steam, which, in the former position of the valve, had forced the piston to the end of the cylinder, would now be liberated, and allowed to exhaust or depart into the condenser, or atmosphere, through E. The traversing motion of the valve, which is effected by the eccentric, thus changes the application of the steam to each end of the cylinder, provides an inlet for the steam to the piston, and also an opening for exhaustion through the proper channels, after power has been exerted, producing a continuous backward and forward action of the piston of the Engine,

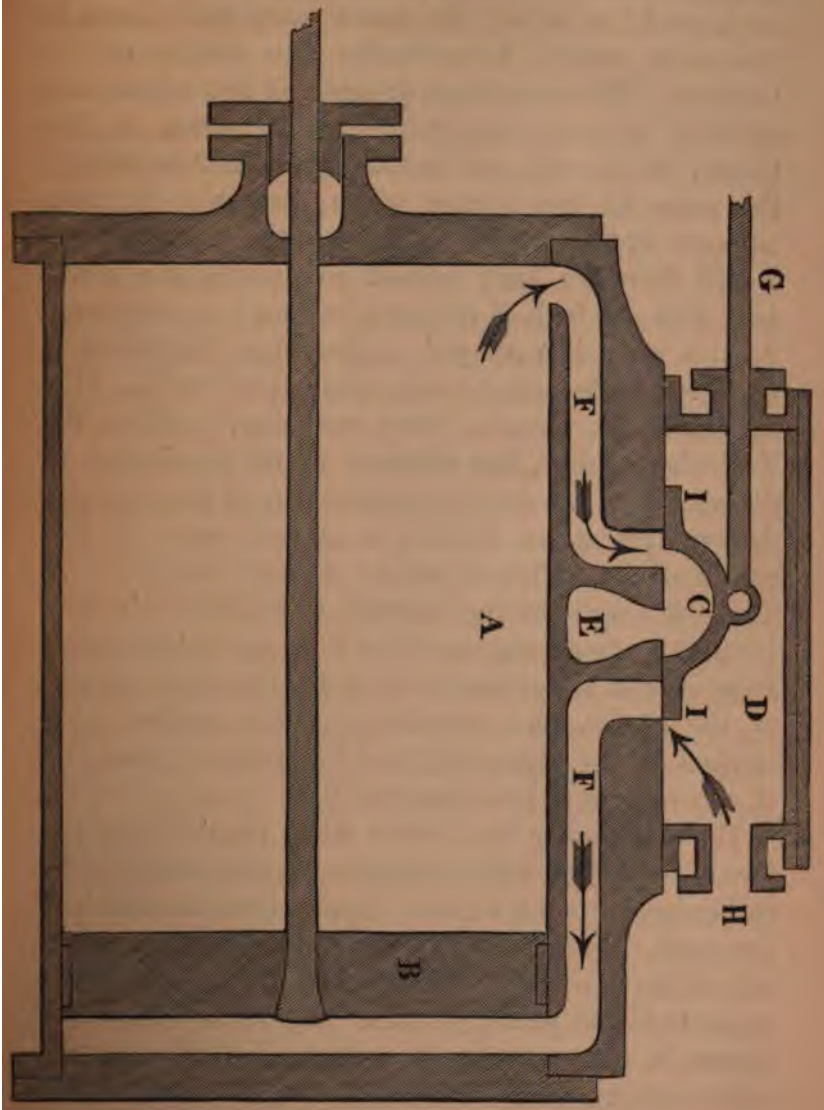
this instance, is already pressed up to the limit of safety, the Engine necessarily consumes a greater quantity of fuel than it would if the steam could be worked expansively.

To enable this valve to cut off earlier and work expansively, without adding "lap," would be to make up part of the thoroughfares at each end of the valve-box towards the outer edge, and cut away some of the metal in the inside of the ports, so that the ports would not be much contracted. In that case the valve would cut off the steam the same as if it had "lap." The hollow of the valve would require to be proportionately less, by being "bitted" in the same way as the thoroughfares. This mode is resorted to when the valve-box is too short, and where "lap" cannot be added to the valve: this is called "lapping the thoroughfares."

"LAP," OR COVER OF THREE-PORT SLIDE VALVES.

Fig. 6 is a representation of a cylinder and a three-port slide valve. The same letters denote the same parts as in Fig. 4. In this instance the valve is shewn with "*lap*" or *cover*, so as to cut off the steam to work expansively. This latter is accomplished to a greater or lesser degree according to the amount of "*lap*" or *cover* of the valve. It will be observed in Fig. 6, that the cover is three-fourths broader than the steam ports, and being worked by the same eccentric, with the same length of traverse, it does not open the steam port more than one-fourth of its width, which in some cases would not be sufficient to admit the full pressure of the steam to the piston; but where the ports are of sufficient width, and a proper pressure in the boiler, no difficulty is experienced by adding "lap" to the valve.

FIGURE No. 6.



Let us ascertain the effect of this additional breadth of valve face. When the valve edge arrives at the port, ready to admit the steam upon the piston, it will have moved three-fourths the length of its traverse. The remaining distance is the amount of opening given for the admission of steam to the piston, which will not be more than half an inch, if the ports be two inches wide: the valve is then reversed by the motion or throw of the eccentric, and it will therefore have opened and closed the steam port with one inch of traverse, half an inch each way. As this valve is V shaped on the edge, the steam is admitted to the piston easily, and cut off easily. This is technically termed "easy steaming." Were the *Indicator* applied, the diagram would be similar to diagram No. 7. At the termination of the piston's descent, the steam is fully exhausted ready for the return stroke. This is called "lead of the exhaust." The full length of the traverse of the valve is four inches for one revolution of the Engine. This arrangement cuts off the steam at about one-fourth the length of the stroke, the remainder of the stroke being worked by the expansibility of the steam. Each end of the valve is of the same width.

The ports being two inches wide, require that the face of the valve, with the same traverse, shall be $3\frac{1}{2}$ inches broad, being $1\frac{1}{2}$ inch broader than the width of the ports. It will also be perceived that the exhaust side of the valve will be three-fourths open when the crank is at the plumb centre. By these means the steam in the cylinder is exhausted ready for the return stroke. The closing of the exhaust is also effected much earlier, whereby the uncondensed steam left in the cylinder becomes compressed towards the

end of the stroke. This in practice is found to act as a buffer to the piston, preventing a sudden shock at the termination and commencement of the stroke. The steam thus compressed is not lost, but gives back a portion of its power on the reversal of the piston.

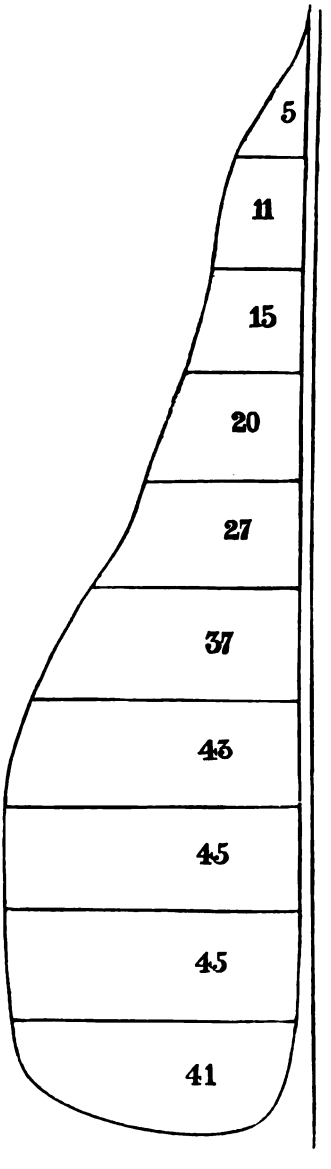
It is necessary for an Engine running quickly, with rapid reversals of the piston, that the valves should cut off the steam early in the cylinder, and the exhaust also close early. The example we have given is considered an extreme amount of "lap" on a three-port valve. Other proportions of "lap," less or more, follow the same principle; that is, if the "lap" or cover be less, the steam will be longer on the piston before it is cut off. The opening and closing of the exhaust will be in like ratio. The traverse of the valve may be increased by a new eccentric, having more throw, or by moving the rock-shaft stud nearer to the centre, providing the valve-box be of sufficient length to enable the valve to travel a greater distance in the same time, by which the ports will be opened wider for the admission of steam to the piston than with its former traverse; and the steam will be cut off at the same point as before, because the valve travels quicker. This is usually termed "travelling over port."

This form and description of the three-port valve and slide is principally used for High-pressure Engines. Various may be the alterations required, according to the width and distance of the ports and the length of traverse, which may be either increased or decreased, if worked by a rock-shaft. The makers of small Portable Engines will find that attention to the form and setting of three-port valves, will be attended with advantage, by admitting the steam to

the piston easily. They should also allow plenty of room in the thoroughfares, so that in the process of exhaustion there be no back pressure, that the speed of the Engine may be increased when more power is required. At the Royal Agricultural Show at Leeds, 1861, there was obsevsable a general defect in this class of Engines—want of speed of the piston, which could not well be increased on account of the fly-wheel being too large. Defects such as these are serious drawbacks upon High-pressure Portable Engines, or to Engines of any other form. Attention to *balancing* the working parts of an Engine steadies the working, and requires less matter to be put and kept in motion to equalise the speed. If the pressure were increased from 45lbs to 70lbs or 80lbs to the square inch (which might be safely effected with small boilers of the portable class), the steam would be used more expansively: consequently, less fuel would be used, and an increased power obtained. We are aware that there is an objection to high-pressure steam amongst the agriculturalists; but how that arises it is difficult to understand, seeing that Railway Locomotives work steam at from 100lbs to 150lbs pressure to the square inch, with perfect safety,—exerting great power, and occupying little space.

Diagram No. 7,

From a High-pressure or Non-condensing Engine.



THE D SLIDE VALVE.

This description of valve, which is in very general use for Condensing Steam Engines, when first introduced was worked without "lap," or extra cover, and the valve-boxes were generally of such a length that they would not admit of the valve travelling over port, consequently the steam was admitted the whole length of the stroke, which caused the exhaust side of the valve to be too late both in opening and closing. For a long period Low-pressure Engines worked in the manner described; but as the property of the expansion of steam became better understood, various methods were adopted whereby the D valve could be made to work on the expansive principle. It was found that by enlarging the valve-box to allow of more traverse, thus giving room for extra "lap," the steam could be cut off at almost any portion of the traverse. This fact was partially known previous to 1841; but in that year a Mr. BOULD, cotton spinner, of Halifax, in Yorkshire, took out a patent for "improvements in Condensing Steam Engines," in which he describes the D valve, and the mode of "lapping." As it appears from his specification that he clearly understood the subject of "lapping" and setting valves, extracts from that specification, in his own language, will be found of advantage. He says:—

"My invention relates to the mode of arranging the valves (which slide over the ports) of Condensing Steam Engines, in such a manner that the exhaustion port shall be fully open at the time the piston has completed its stroke, at either end of the cylinder, and at the same time allow of the steam being worked expansively by means of the same valves. * * *

"In constructing and applying valves to Condensing Steam Engines, the valves of which are worked by eccentrics, it is usual to form the valves of such dimensions that they will only just cover the ports or openings into the cylinder, or only very slightly exceed the dimensions of the port: hence, when the valves are moved, the ports are simultaneously, or nearly simultaneously, opened and closed. * * * By enlarging the size of the slides so that they will be much larger (at least twice as large as the ports they work over), the induction valve may remain closed during a considerable length of movement of the valves; hence it may be closed at any desired part of the stroke of the Engine, and the exhaustion valve remain open to the condenser: and what is also very important, the exhaustion valve may be fully open at the termination of the stroke at either end of the cylinder, so that a good vacuum may at the commencement of the stroke be obtained, and consequently at the time the induction port is open for the flow of steam.

"Fig. 8, represents a diagram of a steam cylinder and valves, and also the eccentrics and parts which work the valves. In Fig. 8, the valves are shewn in the position they would be at the termination of the stroke at the upper end of the cylinder; and it will be seen that the exhaustion valve has passed away from the exhaustion port, and the induction or steam-valve has partially opened the induction port. * * That is not necessary; but if desired, it will be evident to the Engineer that that might be done either by increasing the throw of the eccentric, or by shortening the lever e,[1] to which the eccentric rod is attached.

"Fig. 9, shews a section of a steam cylinder and

NOTE.—Those passages marked s, are the openings of the pipe which convey the steam from the upper to the lower nozzle or valve chest, and the passages marked v, are the openings of the pipe which convey the steam to the condenser.

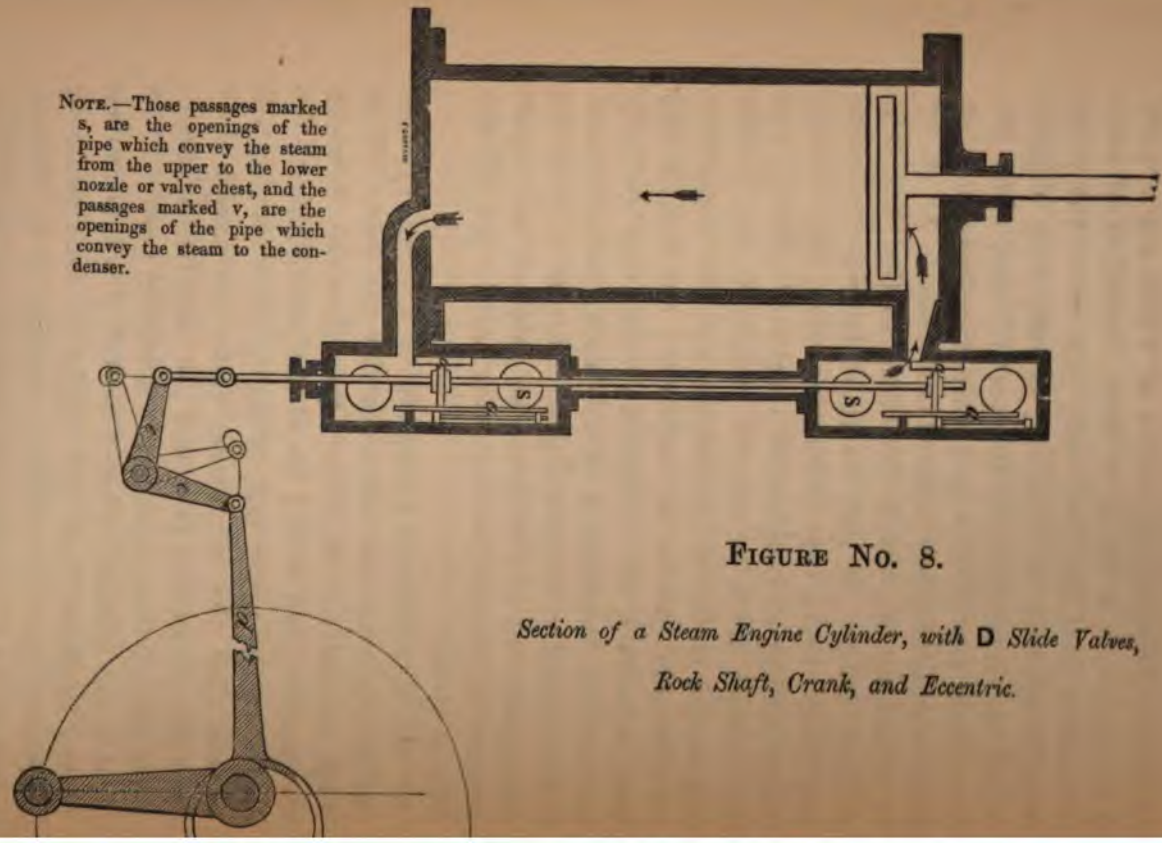


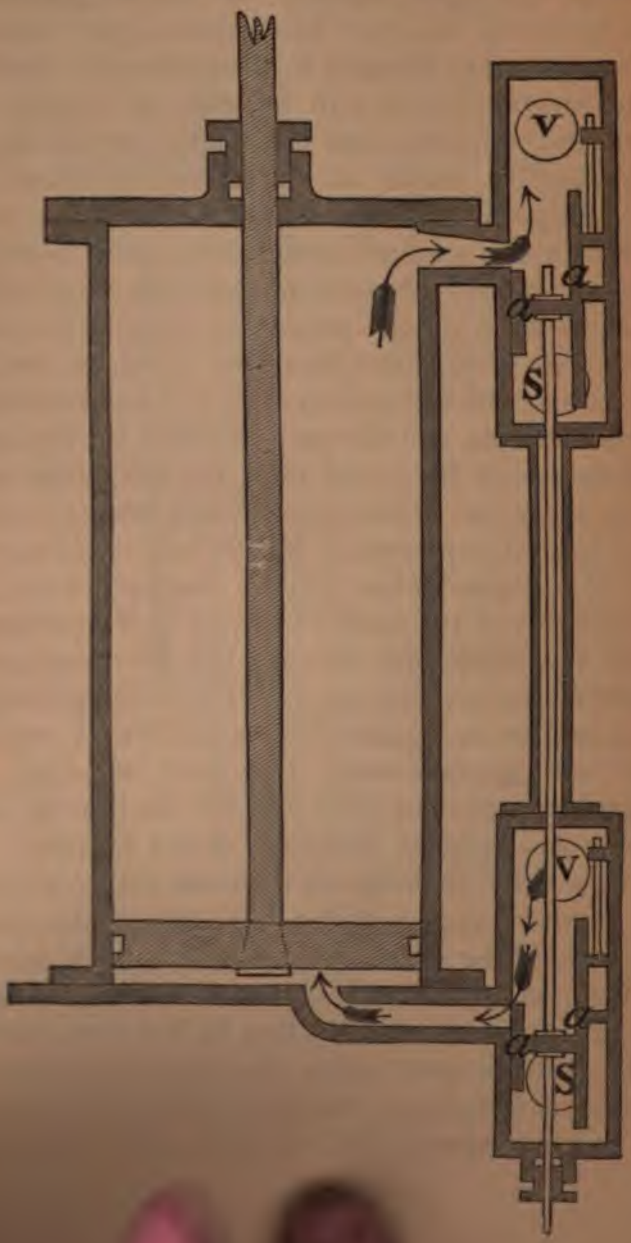
FIGURE NO. 8.

Section of a Steam Engine Cylinder, with **D** *Slide Valves, Rock Shaft, Crank, and Eccentric.*

valves, and the lever which works them, the eccentric which gives motion to the lever not being shewn—the valves in this figure being in the reverse position to that shewn in Fig. 8. The valves *a a* are made of such length as to be equal to three times the opening of the ports; and it will be seen by tracing the movement which will take place in the parts of Fig. 8, that when the stroke in the upward direction has been completed, and the steam or induction valve opened to the required extent, and steam admitted above the piston, the steam or induction valve will be closed by the time the piston has moved about one-third of its stroke; but this may be varied, and the exhaustion port will remain open, and the movement of the eccentric, and the parts actuated thereby, will, near the end of the stroke, close the exhaustion port at the upper end of the cylinder, and bring the parts into the positions shewn in Fig. 9; and it will also be seen that these effects will be consequent on the enlargement of the valves in respect to the ports over which they work, and the extent of movement given to the valves, whereby one or other of the valves can be moved for a considerable length whilst over its port, without uncovering that port, allowing the exhaustion port to be fully open at the time of completing the stroke at either end of the cylinder. At Fig. 8, *b* is the eccentric on the main shaft *c*, and the rod *d* and levers *e* and *e*,[1] for moving the slides. These are of the ordinary construction, allowing only for the quantity of motion given to the valves. And it is important to call attention to the circumstance of the distance over which the valves are moved, as on that circumstance, combined with the length of the valves, depends the beneficial results obtained.

Figure No. 9.

An Enlarged Section of Steam Engine Cylinder with D *Valves.*



Figures 8 and 9 shew the parts so arranged as to cause the valves to move a distance equal to four times the depths of the ports; and if it were desired that the steam port should be opened fully, then the valve would have to move five times the length of the depth of the port; and, in case of making the valves less, to the extent of their being twice the length of the depth of the ports. Then the movement given to them is to be four times the depth of the ports to fully open the steam ports. The movement ought not to be reduced three times the depth of the ports, as the steam port will then be only half opened. It should be stated that although I prefer to work the slides with an eccentric, it will be evident that a crank may be substituted. * * * Although I have shewn the valves as being equal to three times the length of the depth of the ports over which they work, yet I do not confine my claim thereto, as they might be slightly increased, and even less extensive valves may be used, varying the other parts accordingly; but I have found there is little advantage to be derived when the valves are not at least equal to twice the length of their ports, measured in the direction of the movement of the valves. What I claim is, the mode of constructing the valves of Condensing Steam Engines, when worked by eccentrics or cranks, whereby the exhaustion ports may be fully opened at the completion of the stroke, and whereby steam may be cut off, and more effectually worked expansively, by the same valves as above described."

This description of the "lapping" and traversing of the D slide valve, given by Mr. Bould in the specification of his patent, is evidence that if he was not the first inventor of the process, he was in advance

of many Engineers of the day; and there can be no doubt that the publication of his specification supplied information which has enabled other Engineers to improve the working of the Steam Engine.

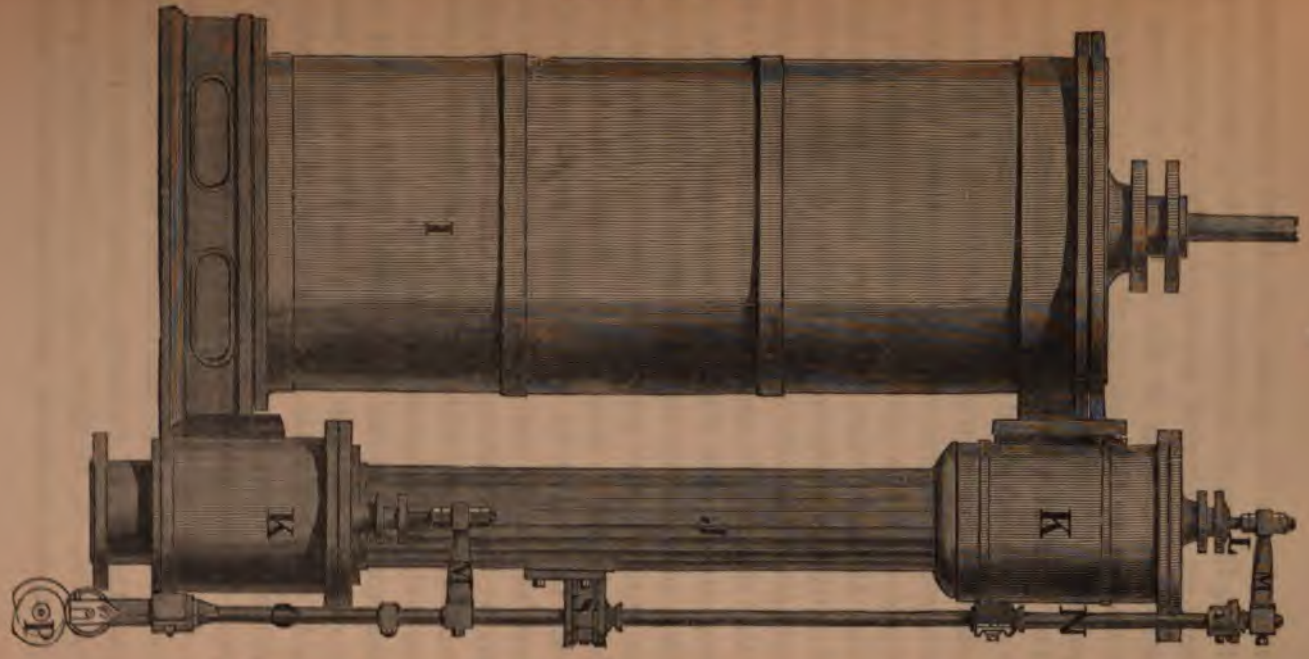
There are other descriptions of cylinder valves than those described, such as the long D, the trellis, the piston, and the single and double drop valves, all of which are one and the same in principle. An Engineer acquainted with the principle of the valves here explained, will have no difficulty in understanding all the various valves in use, and the modes by which they are worked. For the latter, the eccentric movement is in most general use; but there are also the movements of the cam, the tappet, the crank, and the lever.

THE CORNISH OR DOUBLE-BEAT DROP VALVE.

This description of valve derives its name from its first being adopted in Cornwall. In that locality Steam Engines are largely used for mining and pumping purposes, and the piston of the Engine travels at a slow rate. A valve, therefore, that could be closed or opened on the steam and exhaust sides separately, became a useful and important improvement over the old "hand gear" single valve, and also over the three port, or D slide valve.

Fig. 10 is a vertical section of a pair of side pipes of a Steam Engine cylinder, with valves of the Cornish construction. These last are shewn in their respective positions, both on the steam and exhaust
— steam from the boiler enters the steam
takes the direction as shewn by the
ng both at the under and top sides

FIGURE No. 11.



Side View of Cylinder and Side Pipes, with Cornish Valves and Revolving Tappets.

steam valve can be opened and closed at any required distance the piston may have travelled; giving every facility for cutting off the steam, either gradually or suddenly, according to the description of work on the Engine, or the amount of expansion of the steam required.

The exhaust valves have also separate tappets on the same shaft; and as they are required to keep open the valve nearly the full length of the stroke, the tappet is so formed as to cause the valves to open and close at the most advantageous times.

The Cornish valve has two faces, or two inlets and outlets, as shewn by section of valve C and D, which gives a double opening for the ingress or egress of the steam. It also admits of the exhaust valve being raised much higher from its seat, so as to give a free and uninterrupted passage to the condenser. This form of valve possesses a decided advantage over the single faced drop valve. When the tappet has raised the valve to the highest point required, it again falls to its seat by its own weight, and is kept there by the pressure of steam, until the tappet again comes in contact with the pulley at the foot of the valve rod, and is again raised.

On reference to the illustration, it will be seen that the exhaust valve is larger than the steam valve, which, coupled with the extra height the exhaust valve rises from its seat, gives free egress for the steam to the condenser. With *double-beat* valves the steam can be kept longer on the piston before exhausting, because the exhaust valve being large, allows the steam to escape much quicker than the three port, or D slide valve. Where drop valves are used, and worked by a revolving shaft and tappets,

they are much easier to get at by the Engineer than the three-port, or D slide valve. Each tappet being separate, the valves can be regulated separately, either by the shaping of the tappet's circumference, or moving it partially round the shaft, so as to give more or less lead on the steam or exhaust sides of the stroke; or to take off or keep on the steam in the cylinder, according to the load and pressure; thus enabling the Engineer to economise fuel by working his steam more expansively, when less power is required. In this form of valve there is often one defect: the tappets are so formed as to allow the valve to drop upon its seat too suddenly, causing much wear and noise. Were the tappets made to allow the valves to be steadied on to their seats, the valves would keep steam tight much longer, and require repairing much seldomer than in the present construction.

EXPANSION DROP VALVES.

There are various descriptions of Drop Valves for cutting off the steam when the piston has travelled a portion of its stroke, and which are called "Expansion Valves." They are usually worked by a separate eccentric, or by revolving tappets turned by tooth-wheeled gearing, the same as the tappet shaft for working Cornish valves The common single drop valve is inserted in the steam pipe close to the cylinder. It is raised from its seat by a revolving tappet, which tappet is so formed that the valve is held up from its seat to allow the steam to pass through the valve chest and into the cylinder. As the tappet revolves, the full side keeps up the valve during a

portion of its revolution. When the full side has passed, the valve falls back to its seat, and the steam is thus cut off, or prevented passing from the boiler to the cylinder during the time the valve is closed. The length of time steam is thus prevented from passing will depend upon the circumference of the outer diameter of the raised portion of the tappet. Thus, the steam will flow into the cylinder during such portion of the stroke from the beginning of each reversion of the piston, as the length of the circumference of the projecting portion of the tappet which raises the valve from its seat—this being the measure for the "cut off" required. The cylinder valves may work in the usual way, with or without "lap," because the steam from the boiler will have been prevented entering the valve chest during that portion of the stroke the drop valve was on its seat. If the cylinder valves were open on the steam side the full length of the stroke, the steam could only be admitted during that portion of the stroke the drop valve was off its seat. When starting the Engine, the valve can be made so as to be put "out of gear," thus enabling the Engineer to admit the full pressure of his steam upon the piston for any portion of the length of the stroke.

EQUILIBRIUM DROP VALVES.

These are worked by a tappet or eccentric, in the same way as those described above. They are precisely the same in principle, but have two faces or openings, and the pressure of the steam operates on the surface of two valves on the ends of one spindle, the pressure acting on the contrary ends of the valve,

the steam pressing equally in all directions. By this contrivance little power is required to move the valve from its seat. Two openings are effected at the same time for the passage of the steam, thus requiring a very small rise of the valve. This form can also, as in the former case, be thrown "out of gear" at starting, while the Engine has attained its full speed.

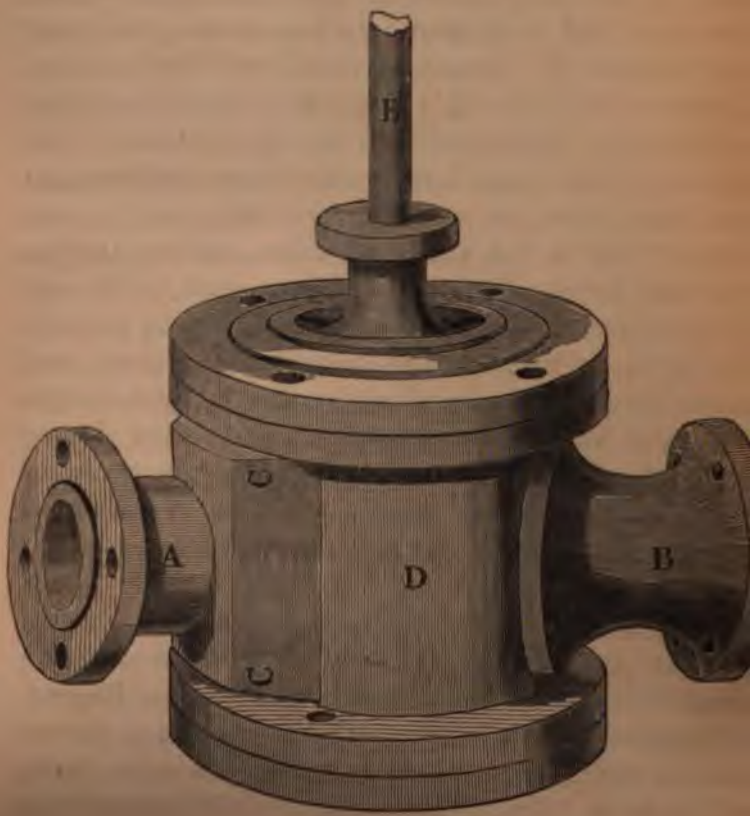
EXPANSION SLIDE VALVES.

Expansion, or Cut off Slide Valves, are generally fitted on the valve chest of three-port slide valves. The valve box is divided into two parts; the lower part contains the three-port valve; and the top compartment the cut off valve. The steam from the boiler is first introduced into the cut off chest. The bottom of this chest has two or more openings into the lower chest, or valve box, which openings are covered with a flat plate, or valve, having therein duplicate holes. This plate is connected to the rod of an eccentric, or the rod may be worked by tappets. The steam is first admitted into the top chest, and passes through the openings in the flat plate to the three-port valve. These openings are closed during any portion of the stroke according as the throw of the eccentric on the tappet may be arranged to traverse the flat valve, so as to cover or uncover the openings. The expansion valve can be made to cut off the steam at such a portion of the piston's traverse as may be found most suitable for the pressure in the boiler and the load on the Engine. Expansion slide valves are sometimes fitted to the back of the three-port slide-valve in the valve chest, and made to take off the pressure of the steam from

the back of the three-port valve. There are a grea variety of expansion valves; but all are nearly th same in principle. The slide cut off, or revolvin principle, is preferred, there being less wear and tea in this construction, than where there is an irregula action as when valves are lifted from their faces, an dropped back again.

FIGURE No. 12.

Revolving Expansion Valve.



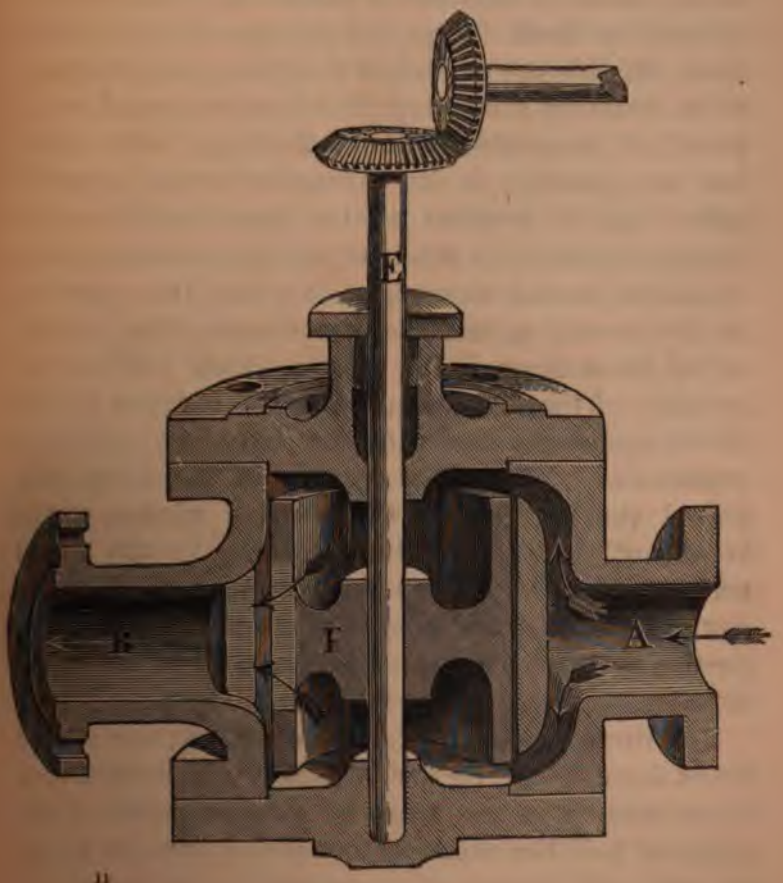
THE REVOLVING EXPANSION VALVE.

The Revolving Expansion Valve is represented in the accompanying engravings, Nos. 12 and 13.

Fig. No. 12 is the outward appearance of the valve. A is the branch pipe connected with the steam pipe from the boiler; D the body of the valve case; C C the thoroughfares at each end of the case; E the

FIGURE No. 13.

Section of Expansion Valve.



valve spindle. At the upper end of the valve case there is a cover which E revolves in, made steam-tight by a gland and stuffing box, and at the other end the spindle E works in a step. The cover is secured by bolts in the usual way.

Fig. 13 is a section of the valve. The arrows shew the entrance and the exit of the steam through the revolving valve to the valve chest of the cylinder. The same letters in both figures represent the same parts. It will be perceived that the steam enters at A, and passes to each end of the valve, which consists of a hollow drum fitting the interior of the circular case. It does not require to fit tightly, as in the case of an ordinary steam tap, but is so arranged as to permit it to revolve without friction. This drum has two openings in its circumference at opposite sides; and it revolves at the same speed as the Engine makes full strokes. As it revolves, these openings present themselves opposite the opening in the branch A, and the steam enters the interior of the drum through the thoroughfares. While the opening of the drum is passing the opening B, the steam rushes forward into the valve-box, which is connected. When the opening in the drum has passed the opening B, the passage of the steam is cut off until the other opening in the drum arrives, which will be at the commencement of the next stroke, and which will continue open in proportion to its own width to the diameter of the drum or valve.

The drum travels half a revolution for one stroke up or down of the Engine. Thus it will be seen that if the opening in the drum be but one-eighth of the width of half the circumference of the drum or valve, the steam will be cut off at one-eighth the traverse of

the piston, or any other portion of the stroke according to the size or width of the opening in the drum. The revolving valve or drum is fitted to a shaft, which may be propelled by bevel or other wheels, and can be made to be put in or out of gear. The action of the revolving valve is very simple—and it can be used as a valve to stop and start the Engine with. A handle wheel can be fixed on the shaft E: when the driving wheels of the valve are thrown out of gear, turn the blank side of the drum against the side of the opening B; the steam will thereby be shut off from the valve-chest and cylinder. At starting the Engine, turn the drum with its opening to the opening B, the steam will then flow the full length of the stroke, if the other valves are without lap, until the Engine has got to the full speed; then throw the wheels into gear, and the valve will revolve and cut off the steam at that portion of the stroke arranged for. According to the opening in the drum the steam may be cut off at any portion of the stroke. It matters not where the commencement of the opening begins, the cut off will be at the time of closing. It will therefore be perceived that any amount of expansion can be obtained by giving lead to the revolving valve; and this can be accomplished while the Engine is working; or the valve may be put out of gear, and full steaming obtained. In the latter case, if the cylinder valves are without "lap" or extra traverse,—for this is not required where an expansion valve of this description is in use,—the steam will be on the piston the whole length of the stroke.

In the descriptions which follow, examples will be given of diagrams taken from Engines where the revolving valve was in use. As before stated, the valve can be used to stop and start the Engine, and

at the same time act as an expansion valve, easily arranged to the amount of expansion required. For Marine Engines it would be a useful and efficient valve, both for regular working and for those cases of necessity where the full power of the steam is at once required. It has been applied to Stationary Engines, particularly to Engines for colliery purposes. It might be advantageously applied to Locomotives, as the expansion would be effected more completely than by the three-port slide valve with "lap" and traverse. When the steam is cut off by this description of valve, the pressure on the back of the cylinder valve is reduced as the expansion of the steam takes place. Under such circumstances, the pressure will be the same in the valve-chest as it is in the cylinder; whereas the pressure on the back of a three port and D slide, with "lap" and traverse, will be the full boiler pressure throughout the working.

The author invented and introduced this revolving expansion valve, and put it into practical use in the year 1844, at several places in Huddersfield, Bradford, Halifax, and Sheffield; and, although the valve was known to many, several years after its introduction it was patented by Messrs. Child, of Halifax, and Mr. Wilson, then of Low Moor; a rather singular circumstance, because Mr. Wilson had seen it at work years before.

There are other forms and descriptions of expansion valves, but they may be said to be one and the same in principle, though differing in form of construction, producing the same results—cutting off the steam and working expansively. An explanation of a flat revolving expansion valve will be given, when we come to describe the Horizontal Condensing Engine, erected at the Britannia Mills, Huddersfield.

EXPLANATION OF DIAGRAMS.

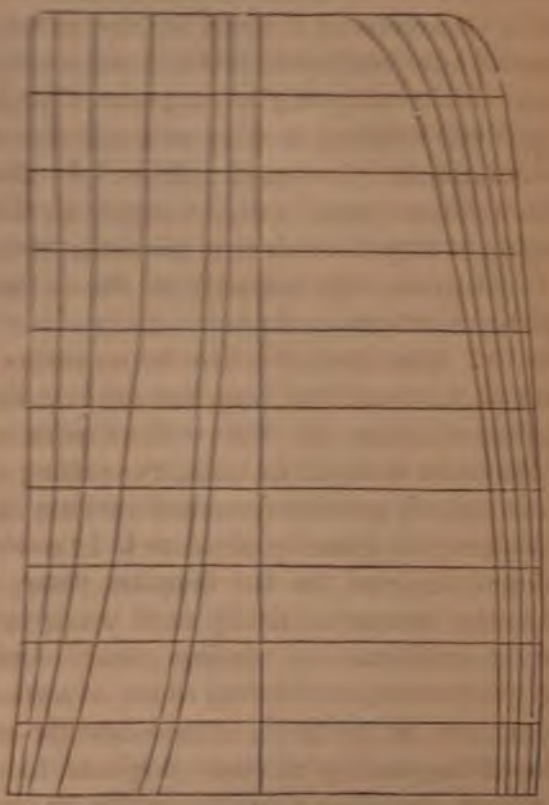
We now suppose the reader to have made himself practically conversant with the principles involved in the construction of the Steam Engine, and with the rules and instructions laid down for his guidance as to the use of the *Indicator*, and the construction of the common slide and other valves; also of expansion valves, and the expansion of steam. If so, he will readily understand the explanations of diagrams which here follow, and be able to apply the instructions therein conveyed to his own case with advantage.

No. 14 diagram was taken from the Engine at Castle Mills, Sheffield, at the commencement of work after dinner. The *Indicator* was in operation until the whole of the work was propelled by the Engine, the diagram showing, by the various lines as the various machines were set to work, the extra quantity of steam required, and the decreased vacuum in proportion to the extra quantity of steam to be condensed. The different degrees on the diagram show, when measured, the power taken by each machine as it was put in motion. A similar result could be obtained where there are different rooms of machinery. Each room, as set to work, would describe on the paper the extra quantity of steam required to propel the machinery, and thus show the value or the cost of the power in each room. By this method we are enabled to ascertain the power required for any particular machine, or number of machines, as well as the most economical amount of power the Engine will

exert, in accordance with its construction, pressure o
steam, size of condenser, dimensions of steam way
and the quantity and temperature of condensin
water available.

Diagram No. 14.

Taken from the Top of Cylinder of a Condensing Engine.



The diagram shews the steam to be on the fu
length of the stroke. The valves were D valves wit
out "lap," consequently the steam was not cut o
before the termination of the stroke. The pressure

the end is lessened, the difference in this case being caused by the condensation of the steam from the low temperature of the cylinder.

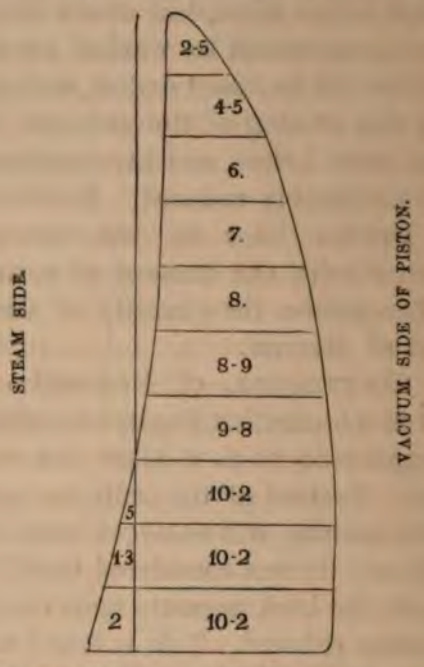
By diagram No. 14 it is shewn that the Engine has large steam ways, as indicated by the great quantity of steam to be condensed at the termination of the stroke. If the eccentric was moved forwards, and "lap" added to the valve, less steam would be used, because the steam would be worked expansively, and the exhaust would be closed earlier, making a diagram rounded at the closing of the exhaust. The Engine would then work better, and the consumption of fuel would be considerably reduced. It will be observed that the various lines on the vacuum side are in accordance with the amount of steam to be condensed. The greater the quantity of steam, the less the amount of vacuum.

Messrs. HAWTHORNE, of Newcastle-upon-Tyne, introduced to Locomotive Engines an additional valve on the exhaust side, so as to allow the steam to pass out quicker. Instead of the ordinary opening of the exhaust, the opening was enlarged more than double, by two outlets. It was considered that if the exhaust was enlarged, the back pressure upon the piston would be considerably reduced. This is found to be the case when the piston travels at a great speed—and the principle is now carried out by some makers. We cannot see why Stationary Engines should not be altered upon the same principle. Were this the case, in many instances the vacuum would be greatly improved, and considerable saving of fuel the result. The lead of the exhaust, with ordinary valves, has to be put forward to allow the steam to escape, so that the piston may not be obstructed in its return—thus

losing that portion of the power in the steam which is prevented from following up the piston to the end of the stroke. Where Cornish, or drop valves, and where valves on the trellis principle, are used, the

DIAGRAM No. 15.

Taken from the Top of Cylinder of a Condensing Engine.



Steam 0·3lb. 7·7 Vacuum.
0·3 Steam.

8·0lbs. Average Pressure.

exhaust ports can be opened much quicker than with the ordinary slide valve; and it is often remarked that an Engine with the before-named valves "works stronger." This may be accounted for, because the exhaust valve may remain closed longer, thus following

the piston with the steam near to the end of the stroke, and thereby obtaining more power than by the other modes of admitting and discharging steam from the cylinder.

In diagram No. 15 we have the opposite of No. 14. This Engine, although of nearly the same nominal horse power, would not be able to move with the load No. 14 Engine drives. The steam ways are so very small that the steam in the boiler cannot exert its force upon the piston, for want of more space in the pipes and passages to the cylinder. For want of lead on the exhaust side, the steam cannot leave the cylinder at the proper time, as is fully shown by the diagram. For want of room in the thoroughfares for the steam in the cylinder to escape into the condenser, the Engine makes a very indifferent vacuum at the termination of the exhaust, only 10·2lbs, although there were plenty of cold water to condense with; or, in other words, a large quantity of steam is left in the cylinder uncondensed, and exerts a resisting force to the motion of the piston. This has to be made up by an extra quantity of fuel, involving a great loss of power. It involves also extra expense for the wear and tear of the boiler and furnace, and entails additional labour.

The vacuum is very indifferent, $7\frac{1}{10}$lbs. The average throughout the stroke is nearly 3lbs less than No. 2 diagram, and there is less pressure of steam upon the piston: No. 2 having an available power of 12lbs on each square inch of the piston, and No. 15 an available power of 5lbs—not one half of No. 2; No. 15 consuming more fuel for less than half the work done. The steam in passing from the cylinder to the condenser in such an Engine as No. 15, will make a

great noise. This description of noise has been often mistaken for, and stoutly maintained to be, the effect of a good vacuum, by those who are not conversant with the use of the *Indicator*. The noise is produced by the steam pressing its way through the confined passages. Had the steam sufficient room to travel unobstructed, the noise would cease, because the speed and the pressure would be reduced by the larger openings: the same as a wide chimney to a furnace allows the smoke to pass off easier and quicker at the same time. Although the thoroughfares to the cylinder and the valves are too contracted, the best is not made of them under the circumstances. The valve ought to have more "lap," so as to cut off the steam earlier, and the exhaust be opened and closed earlier. If the valve traversed quicker, the thoroughfares would be opened quicker, thus admitting the steam to the piston faster, after the ports begun to open, and allowing it to depart sooner. The vacuum would be thereby improved, less steam would be required, and the Engine would work better.

There are many Engines working similarly to the one above described. Neither the proprietors nor their Engineers know but that all is right. Not seeing the interior action from a diagram, or not knowing how to take one and work it out, they do not perceive their loss.

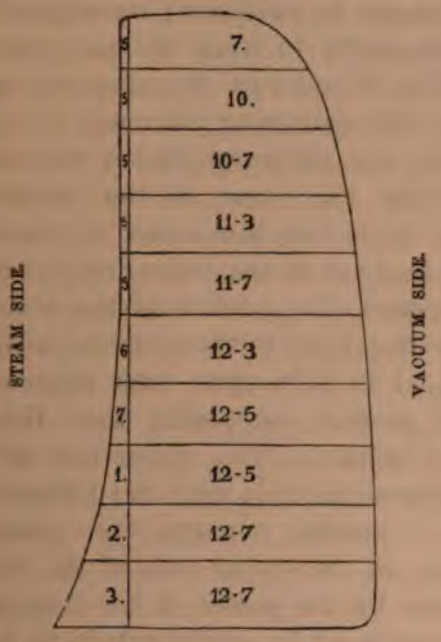
Diagram No. 16 was taken from the same Engine, when new side pipes of larger dimensions and D slide valves had been applied.

Here the vacuum is greatly increased, and the power of the Engine also, though consuming only the same quantity of fuel. Still, both No. 15 and No. 16 are very defective. A great improvement in the

working of the Engine would be effected by giving the valve more "lap" and more traverse; or, in other words, the eccentric or tappet motion requires to be put forward, so as to open the exhaust sooner, and

DIAGRAM No. 16.

Taken from the Top of Cylinder of a Condensing Engine.



Steam 1·0lb 11·3 lbs Vacuum.
1·0
12·3 lbs Average Pressure.

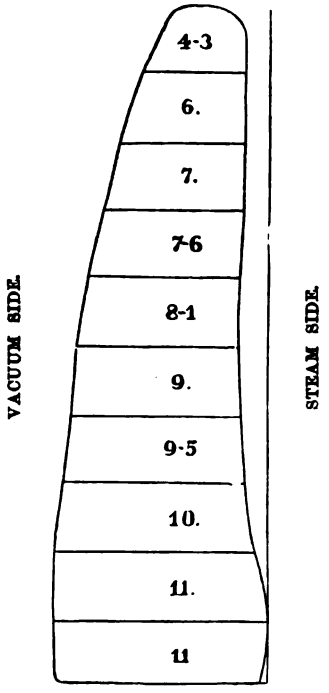
close it sooner, and the valve requires to be made longer at each end to overlap the steam ports, the technical term being "more lap of the valve,"—(see explanation on the setting of valves, at pages 66 to

72, on D valves with "lap"), so that the pressure of the steam in the boiler would be more upon the piston at the commencement of the stroke, and would be cut off before the termination of the stroke. This would give more lead to the exhaust, enabling the steam to work expansively, the same as in No. 2 diagram. This would result in a great saving of fuel, and require less water for the condenser, there being then less steam to condense; consequently it would require less power to work the air-pump. The less the quantity of water in the air-pump may be, and the longer the delivering valve will be kept closed. The further the air-pump bucket can travel up the barrel before the force of the water opens the delivering valve, and the better it must be for the Engine. As soon as the delivering valve of the air-pump is opened, the pressure of the atmosphere acts with a resisting force to the up stroke of the air-pump bucket equal to 15lbs upon each square inch of its superficial surface, supposing that there be that amount of vacuum. The under side of the bucket having a communication with the condenser, in which there is a partial vacuum, the pressure of the atmosphere on the upper side of the bucket has to be overcome by the power of the Engine—an application of power which ought not to be lost sight of. In proportion to the distance which the bucket of the air-pump has to travel with the pressure of the atmosphere upon it, in that proportion does it require more steam to work the Engine, and consequently more fuel and more water, for want of the valves opening and closing at the proper time. In this case the air pump has more water to lift than it need have; therefore, the delivering valve of the pump is opened

much sooner, and the pressure of the atmosphere pressing upon the upper side of the pump bucket, acts in opposition to the traversing of the bucket with a force as explained above. *

Diagram No. 17.

Taken from the Bottom of the Cylinder.



Average vacuum, 7·2lbs.

No. 17 diagram was taken from an Engine belonging to Mr. John Davison, corn miller, Gateshead, which has since been destroyed by the great fire at

* Former editions of this Work having directed the attention of the Proprietors and Engineers to the defects of the above Engine, they have now each an Indicator, and have, to great advantage, adopted the alterations suggested.

Gateshead and Newcastle-upon-Tyne. The pressure of steam in the boiler was 10lbs to the square inch above the atmosphere. This Engine was supplied with cold water from the river Tyne; therefore that useful agent for the Condensing Engine was in abundance. The valves were two short slides—the pressure of the steam upon the back of the valves pressing them to the face. These slides required considerable power to work them—a consideration that should not be lost sight of in the construction of an Engine, particularly where high-pressure steam is used.

This diagram gives another example of contracted steam ways, and shews the crippled state of the Engine. The average pressure upon the piston is 7·2lbs to the square inch, with steam in the cylinder at atmospheric pressure at the commencement of the exhaust. Deduct the friction of the Engine and shafting at the regular allowance, 3lbs to the square inch, and the available power remaining is 4lbs to the square inch. Compare this diagram with diagram No. 2. The average pressure upon the piston in No. 2 is 15lbs to the square inch, with steam in the cylinder at the commencement of the exhaust 6lbs below the pressure of the atmosphere. The one Engine has to condense fourteen, and the other nine, making a difference of thirty per cent. in favour of No. 2 Engine in the steam used and the steam to condense; showing the superiority of one Engine over the other. No. 2 diagram shows 15lbs to the square inch, which with 3lbs for the friction of the Engine and shafting taken off, leaves an available power of 12lbs to the square inch upon the piston—or three times the power of No. 17, with thirty per cent. less fuel used, and thirty per cent. less water for condensing.

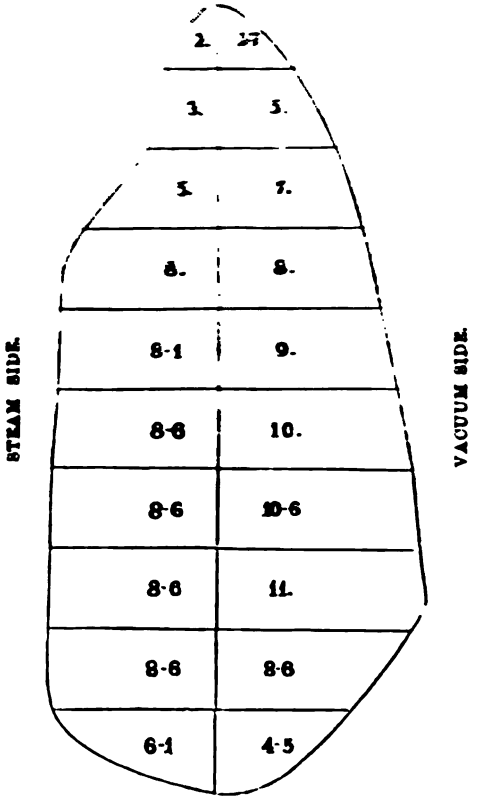
The maker of the Gateshead Engine prided himself upon the superiority of this Engine over others, from the great noise the steam made on the exhaust side—he mistaking the noise for a good vacuum, when, as shown by the diagram, the contrary was the fact. At this mill there were two Engineers at work, two Engines, two sets of boilers, and more than four times the quantity of fuel used than was necessary. Had the Engine No. 17 been properly constructed, it would have been able to propel more than both Engines were propelling, to say nothing of the daily expenditure being at least three-fourths reduced, and leaving out of question the wear and tear, and the space uselessly occupied. Had either the maker or the proprietor been practically acquainted with the *Indicator*, it would have been of advantage to both. If the one had made a mistake, the other would have been able to point out the defect, and between them the Engine might have been put in proper working condition. Instead of this, however, they were both satisfied with it in its crippled condition; the one believing that he had constructed an Engine which could not be exceeded, and the other believing that his Engine was one of the best. As a proof that it was a good one, several people were called in to hear the good vacuum the Engine was making. The noise produced by the exhaust was similar to the noise made by the escaping steam at the top of a Locomotive Engine chimney. This is not a solitary instance of this kind of Engineering, but a sample of what may be frequently met with.

No. 18 diagram was taken from an Engine belonging to Mr. Ricketts, corn miller, Sheffield. By this diagram the state of the Engine will at once

[illegible] apparent. The steam was too late, the exhaust wa[illegible] was not, and also closed too soon. In this state th[illegible]

Diagram No. 18.

Taken from the Engine's Condensing Engine Cylinder.



Steam 6·66lbs. 7·64lbs. Vacuum.
6.66 Steam.

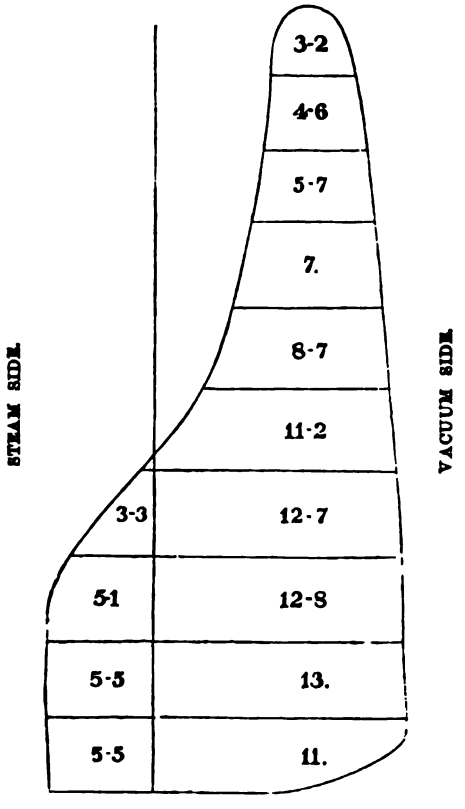
14·30 Average Pressure.

Engine worked for a considerable time. There was [illegible] most irregular motion, causing the stones to trembl[illegible]

and the whole machinery to appear in an agitated state. The Engine was consuming a great quantity of fuel, and by most parties it was considered over-

DIAGRAM No. 19.

Taken from the Top of the Cylinder of the same Engine as No. 18.



Steam, 1·94lbs.

8·92lbs Vacuum.
1·94 Steam.

10·86 Average Pressure.

loaded. The valves were of the conical description, worked by revolving tappets. Several Engine-makers

had examined the Engine, and various were their conjectures. At length, as a remedy, one of them applied several tons of metal to the rim of the fly-wheel. The result was not as anticipated: the additional weight—which had to be propelled!—did not improve the working, and the conclusion come to after this alteration was, that the Engine was too small for the work it had to do. Diagram No. 18 was taken when the Engine was in this state.

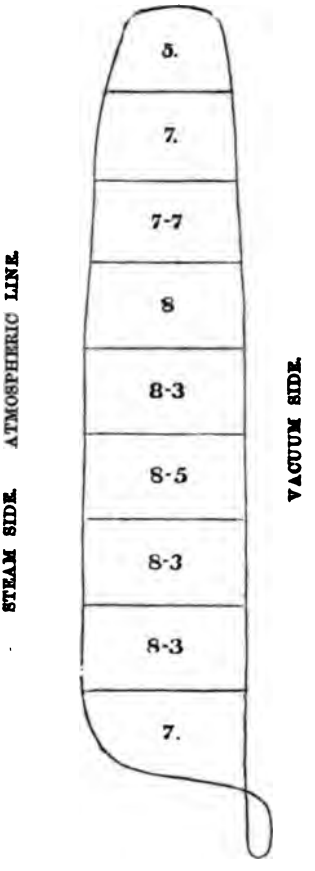
Diagram No. 19 was taken from the same Engine, in the short space of one hour after the *Indicator* had been applied. The tappets which worked the drop valves had moved from their places, as will be seen on reference to No. 18 diagram. The tappets were adjusted, the *Indicator* again applied, and No. 19 diagram obtained.

Examine the difference: the improved vacuum—the steam on at the proper time, cut off at one-fourth the length of the stroke—working by expansion—and the exhaust sooner. The average pressure of No. 19 diagram is 10·86lbs, and the average of No. 18 diagram 14·30lbs; thus showing that the Engine, before the valves were properly set, was consuming steam equal to 3¾lbs to the square inch to work itself more than No. 19. The result of the alteration was, that the Engine consumed little more than half the fuel it did before, the stones run steadily, the whole machinery at the proper speed, and sufficient surplus power remained to have driven one-third more work. This case shows pre-eminently the advantage and use of the *Indicator* over the guess-work of some Engine- and managers of Steam Engines. By its use ts were at once laid bare, and the simple

Diagram No. 20 was taken from an Engine onging to Mr. SWIFT, of Mirfield. Here was ›ther example of valves improperly set. The

DIAGRAM No. 20.

Taken from the Top of the Cylinder of a Condensing Engine.



gine, in passing the centres, started and jumped a strange manner, shaking the Engine-house. eral opinions were given by Engineers as to the

591532 A

cause of this defect. One said it required new side-pipes and valves, and recommended them accordingly. Another Engine builder declared the Engine required a thorough examination and repair.

The *Indicator* was applied, and the valve was adjusted during the dinner hour. The defect proved to be, that the valve was too late at one end, and too soon at the other. The valve spindle only required adjusting at the cross head, which was done, and this was found to be an effectual remedy, except that there was very little "lap," the valve being a long slide.

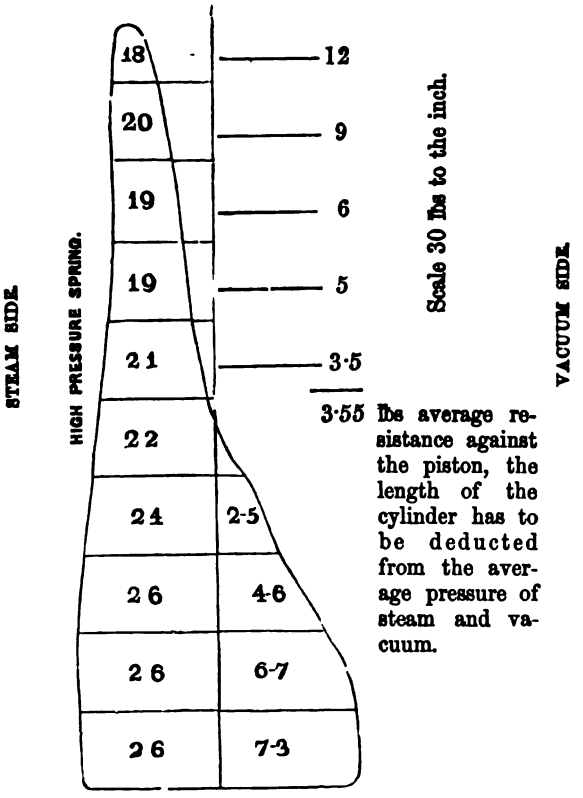
Could "lap" have been added, and the steam cut off earlier, a less quantity of steam would have done more work, and a better vacuum would have been made.

Diagram No. 21 was taken from an Engine belonging to the firm of Messrs. NAYLOR, VICKERS, AND Co., Sheffield. The pressure of steam in the boiler was 45lbs to the square inch above the pressure of the atmosphere. The diagram shews a pressure of 26lbs to the square inch above atmospheric pressure at the beginning of the stroke, and 20lbs at the end of the stroke. The condenser could not condense such a large quantity of steam in sufficient time; consequently, there was a back pressure upon the piston of 12lbs to the square inch above atmospheric pressure, and no vacuum was formed until the piston had nearly completed its stroke. Then at the extreme, there was only a vacuum of 7lbs. Here was a Condensing Engine working with high-pressure steam without expansion, the steam retained in the condenser and pipes, offering a great resistance to the piston, and the air-pump loaded with water, requiring much power to work it. Had the steam been allowed

scape into the open air, the working of this ine would have been better; or, had the exhaust

DIAGRAM No. 21.

'aken from the Top of the Cylinder of a Condensing Engine.



Steam 22·10lbs. 2·11lbs Vacuum.
22·10 Steam.

24·21 Average Pressure.

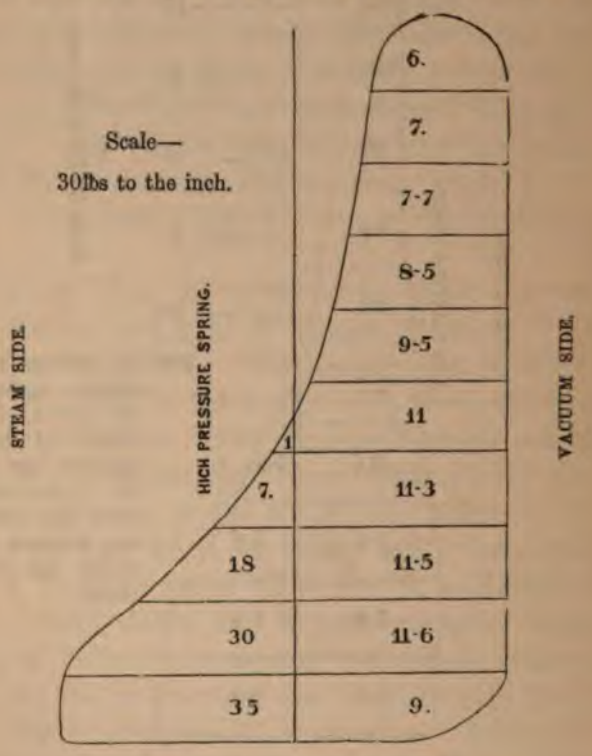
n set forwards, and the valve made to cut off the ım at one-half the stroke, the advantage would

have been great, but not so much as was otherwise obtained. The valves were of the D construction.

Diagram No. 22 was taken from the same Engine, after an expansion valve had been added—a revolving

Diagram No. 22.

Taken from the Top of the same Engine Cylinder as No. 21.



Steam 9·1.lbs. 9·31lbs Vacuum.
9·01 Steam.

18·32 Average Pressure.

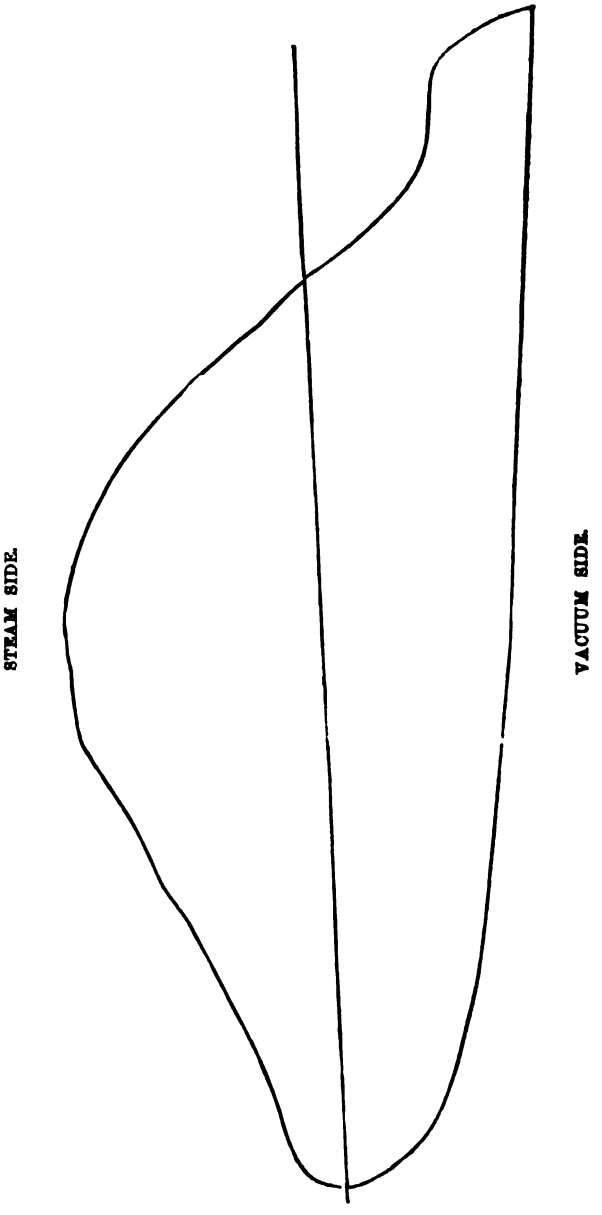
valve, cutting off the steam at any required portion of the stroke. (The description of the revolving expan-

sion valve will be found at pages 81 to 84). For No. 22, the steam in the boiler was at the same pressure as when No. 21 diagram was taken. No. 22 diagram tells a very different story to that of No. 21. The expansion valve cuts off the steam at one-sixth of the stroke, and the effect of the alteration was, that there was a pressure of steam upon the piston of 35lbs above atmospheric pressure at the beginning of the stroke, expanding to 6lbs below the pressure of the atmosphere at the end; so that there was 26lbs less steam to condense in No. 22 than in No. 21. As shewn by the diagram, the vacuum is 11½lbs at the extent. This last fact is accounted for by the small size of the condenser, it not being proportionate to the size of the steam cylinder—a defect far too common with Condensing Engines, occasioning a loss of fuel proportionate to the decreased vacuum. When this is the case, the condensing water should be introduced to the steam in the exhaust pipe before it enters the condenser. The water traversing along with the steam into the condenser, tends to condense the latter quicker and better.

The saving of fuel effected by the simple alteration above described, was more than one-half, although the vacuum was not so good as it would have been had the size of the condenser been in proper proportion. No. 21 is an example of the steam on one side of the piston acting against steam on the other side, and also of a want of knowledge of the expansive property of steam—the Engine expending a great portion of the power upon itself, as shewn by the diagrams. In No. 21 the average pressure is 24·22lbs, and in No. 22 the average is 18·32lbs; a great difference, especially when it is considered that the

Diagram No. 23.

Taken from the Top of the Cylinder of a Condensing Engine.



extra power was totally lost, causing also an additional strain upon the Engine, destroying its parts, and involving great wear and tear. The proprietors were not aware of any defect in this Engine until the *Indicator* had been applied. That application was the cause of the revolving expansion valve being added, of the D valves being properly adjusted, and also of the crippled size of the condenser being made apparent. On examining the diagram it will be perceived that the steam does not expand down according to mathematical rule, because the steam in the side pipes supplies a portion of that of the cylinder; thus reducing the pressure on the piston gradually, and preventing, to a great extent, the shock caused where the steam is cut off too suddenly.

EXAMPLES OF DERANGEMENT OF VALVES.

Diagram No. 23 was taken from one of a pair of Engines, coupled together, belonging to Messrs. HYDE, SONS, AND SOWERBY, of Duckinfield. The Engineer, observing that one of the Engines did not work with its usual smoothness, applied the *Indicator*, and obtained the diagram here given, which shews that the valves had become deranged, and were working very irregularly. The steam was too late and the exhaust too soon. The vacuum also closed too soon. In fact the valves were opening and closing by no rule; and had not the two Engines been coupled, a stoppage must have taken place without any apparent cause. Who could have accurately defined the defect, if the Engine had been examined in the ordinary manner? It might have been sought

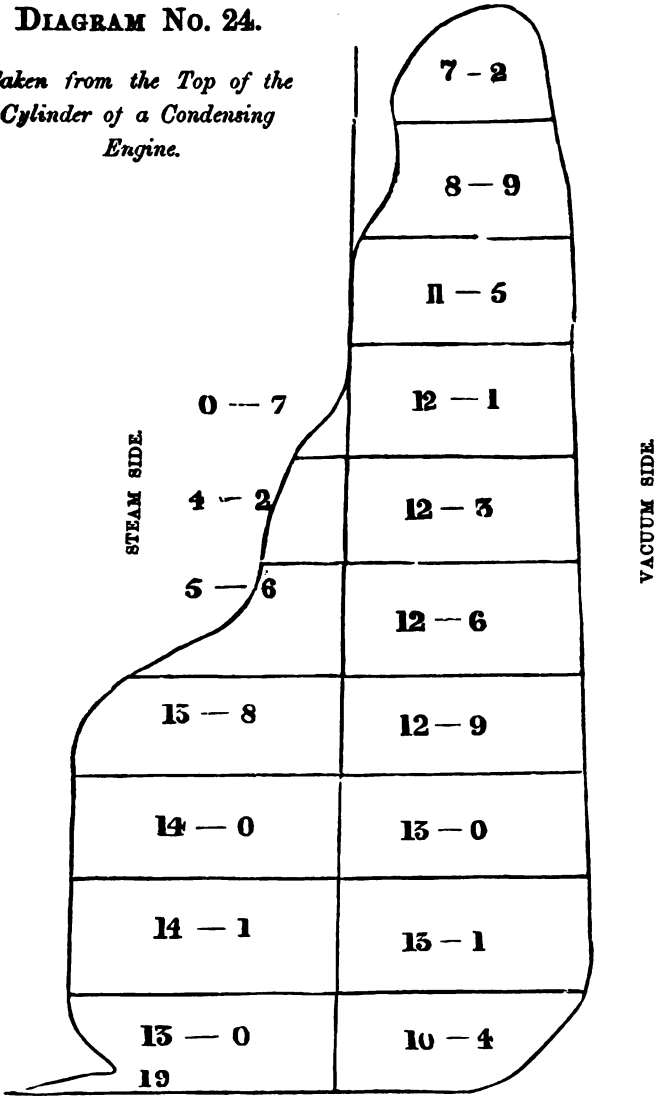
in vain, and the Engine pulled to pieces before the defect had been discovered—a practice too often resorted to, entailing great expense and loss of time to rectify a trifling derangement. The *Indicator*, however, enabled the Engineer, Mr. E. GLEDHILL, to ascertain and remedy the defect. After he had obtained the diagram (No. 23), he at once set down the Engine, and traced the irregularity of the working of the valve to the giving way of a key in one of the driving wheels of the valve gear. In a short time all was put right, and the two Engines were again at work.

This case shews how easy it is to prevent accidents where an Engineer is conversant with the use of the *Indicator*, and understands a diagram when taken. Had it not been for the aid of this invaluable instrument, the damage to this Engine would probably have been serious. This shews how important it is that a person in charge of an Engine should have a thorough knowledge of the use of the *Indicator;* for without its aid, in this case, it would have been impossible to detect the derangement while the Engine was at work. Had the Engine broken down, the real cause of the disaster would in all probability have remained unexplained.

Diagram No. 24 was taken November 24th, 1855, from another Engine belonging to Messrs. HYDE, SONS, AND SOWERBY. This diagram is also illustrative of our present subject, "Derangement of Valves;" and as there are numerous Engines working with valves set in a similar manner, it is important that the facts and particulars of the case should be fully entered into and attentively considered; because a mistaken opinion exists amongst Engineers as to the

Diagram No. 24.

Taken from the Top of the Cylinder of a Condensing Engine.



Steam, 6·54lbs.

11·40lbs Vacuum.
6·54 Steam.

17·94lbs Average Pressure of the steam on the piston throughout the stroke.

cause of the irregularity which the diagram exhibits. Many suppose that the irregularity of the figure is caused by the irregularity of action in the *Indicator*, arising from a want of correctness in the working parts, or from the spring of the instrument being too weak. In the present instance this idea prevailed; and, as a proof that the irregularity arose from this cause, other diagrams were taken by a differently constructed *Indicator*, with the pencil projecting at a right angle from the cylinder—the barrel, or cylinder to which the paper is affixed being detached from the body of the instrument. This latter description of *Indicator* is not sensitive enough to shew the true action of the steam upon the piston of the Engine, because the pencil-holder, with the pencil in the position described, acts as a lever with a motion opposed to the motion of the piston, and adds additional friction, preventing a true tracing on the barrel of the *Indicator*. It thus arose that the valves of the Engine from which diagram No. 24 was taken were in the state shewn, because the *Indicator* formerly used did not exhibit the irregularity made apparent when a larger and more sensitive instrument was applied. It will be seen from the diagram that on the steam side, at the commencement of the stroke, the steam is exerting a pressure upon the piston of 19lbs per square inch, the crank being then at the plumb centre. As soon as the crank has turned the centre, and the piston moved forward, the pressure of the steam is reduced to 13lbs per square inch. Then again it is raised to 14lbs, until the valve begins to close nearly at the half-stroke. It will be observed that here another irregularity occurs, which was said to be produced by the faultiness of the *Indicator*. In

many instances where similar diagrams are taken, these irregularities are considered to arise from defectiveness in the instrument. Of course it is much easier to blame the *Indicator* than to explain its action. But to proceed with our description : the diagram shews that the steam was forcing the piston of the *Indicator* upwards against the spring, the resistance of which was equal to a pressure of 19lbs per square inch. Were not this so, how could the piston have been sent up? There must have been sufficient force to overcome the resistance of the spring. This extra pressure at the beginning of the stroke—top and bottom—has a very injurious effect upon an Engine, and is the cause of more break-downs than almost all other causes put together. Were the art of valve-setting more fully understood, so as to bring judiciously the pressure of the steam to bear upon the piston, we should seldom hear of Engines being stopped to repair break-downs, which are now of constant occurrence, from the cause just explained.

Wherever the *Indicator* makes a diagram similar to that of No. 24, it will be found that there is a great strain upon the pillars, beam, centres, crank, and other fixings of the Engine, which may be easily detected by placing the hands upon the parts.

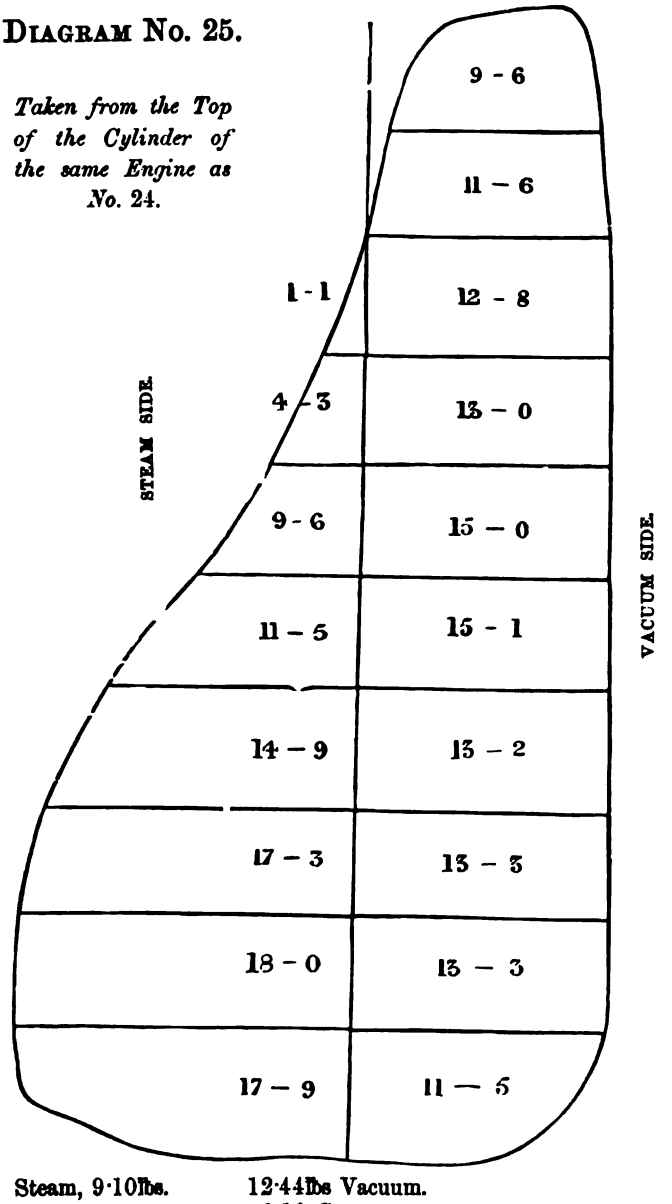
In diagram No. 24 the pressure of the steam in the boiler was 25lbs to the square inch. The diagram gives an average pressure throughout the stroke of 17·94lbs to the square inch. The average pressure of steam above atmospheric pressure is 6·54lbs, with a pressure upon the piston at the commencement of the stroke of 19lbs per square inch above the atmosphere. This extreme pressure being imparted to the crank at "plumb centre," every part of the Engine was thereby

subjected to severe strain, there being on the beam, crank, and centres, a dead lift twice during every stroke. This was the result of the valve having too much lead, and of opening too quickly, so that the rush of the steam struck the piston of the Engine with great force in the same way as steam is applied to "the steam hammer." This caused the Engine to tremble, and be, to all appearances, heavily loaded. At the closing of the valve at half-stroke, the steam was reduced down too quickly. The diagram shews that the valve closed too rapidly, causing vibration and unsteadiness from the irregularity of the pressure upon the piston. This diagram exhibits the evil of steam being cut off too quickly, instead of being shut off regularly and easily: for it is as important for the steam to be taken off easily as for it to be let on easily, that the steady working of the Engine may not be disturbed. In the case we are considering, had there not been a heavy fly-wheel to overcome the sudden changes occasioned by the steam being thrown on and cut off too quickly, the vibration would have been much greater.

This mode of setting valves, with too much lead, of which diagram No. 24 is an example, is a relic of the olden times, when low pressure steam was used from 4lbs to 10lbs per square inch. The practice is not nearly so objectionable with low pressure as with high pressure steam. Had there been a proper *Indicator* in use at the time we speak of, we should not now have had to combat the deep-rooted prejudices and mistaken opinions which prevail amongst those who have been in the habit of using the small *Indicator* with its pencil fixed contrary to the traverse of the *Indicator* piston. We shall have to shew in

Diagram No. 25.

Taken from the Top of the Cylinder of the same Engine as No. 24.



Steam, 9·10lbs.

12·44lbs Vacuum.
9·10 Steam.

21·54 Average Pressure of the steam on the piston throughout the stroke.

our further explanation of diagrams the evils which result from this description of instrument, and the injury done by parties who, without consideration, report on Steam Engines from diagrams taken by this defective instrument. In so doing, we shall give practical examples and facts to bear out our representations. We have only one object in view, that of dispelling the errors of those who ought to be more fully acquainted with the use and utility of a sensitive *Indicator* for valve-setting; and unless we give the names of the parties, and the circumstances we are commenting upon, others might be blamed. Since the publication of the practical facts contained in the early editions of this work, a great change has taken place amongst practical Engineers in the use of the *Indicator*, particularly in valve-setting, where great nicety is required.

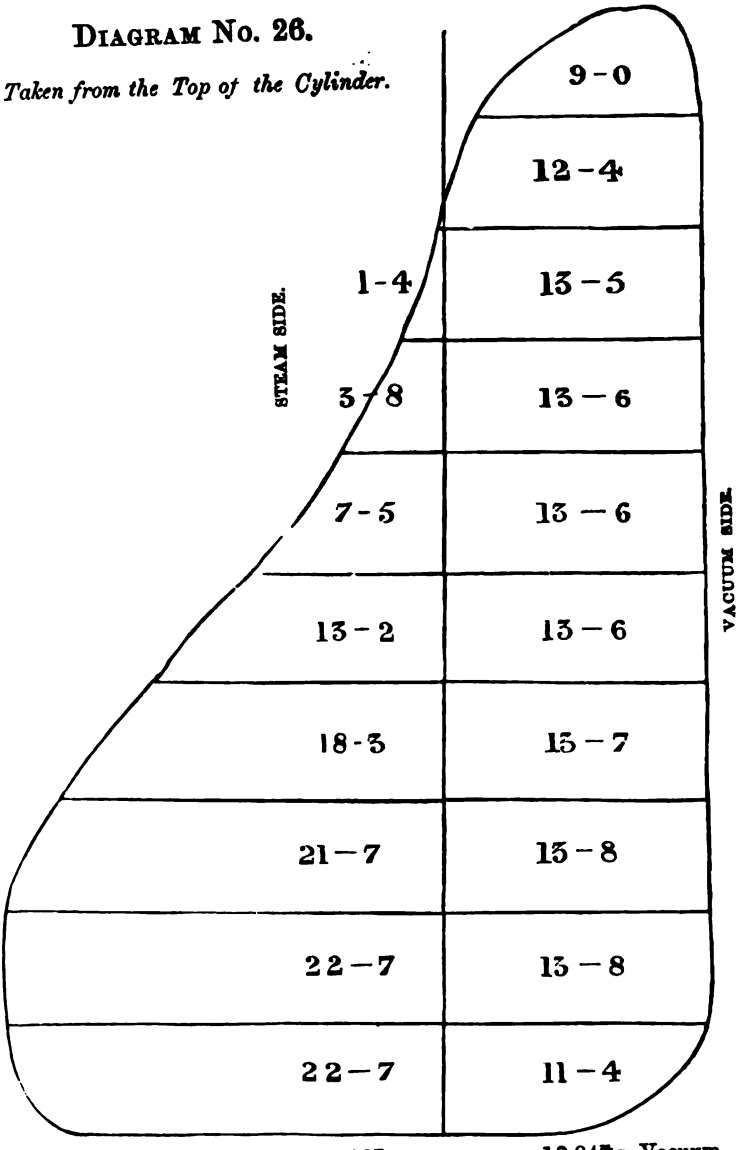
Diagram No. 25 was taken March 12th, 1856, from the same Engine, and by the same *Indicator*, after the valves had been adjusted so as to apply the steam easily at the commencement of the stroke, and also to cut it off easily. We here see that instead of the corner of the diagram on the steam side having a projecting point, the corner is rounded, because the full pressure of the steam on the piston is not applied until the crank has passed the centre, thereby preventing a dead lift at the foundation, the beam, the centres, the crank, and the pin. It will also be observed, that on the valve closing short of the half-stroke, it closes regularly, and the diagram does not exhibit the variations which are shewn in diagram No. 24. The pressure in the boiler when diagram No. 25 was taken was 25lbs to the square inch, the same as in No. 24; average pressure on the steam

side of the piston, as shewn by the diagram, is 9·10lbs, and on the vacuum side, 12·44lbs :—average, 21·54lbs per square inch, being 3·60lbs more than with diagram No. 24; shewing the Engine to be exerting twenty per cent. more power, with less strain upon the various parts than before. The greatest pressure in No. 24 diagram is 18lbs above the atmosphere, and that is after the crank has passed the centre, that being a more favourable position to receive the full pressure. After the valves had been altered, and more work put on the Engine, the straining of the parts was comparatively removed, as shewn by the diagram; another instance of the correctness of the *Indicator* in describing the changes effected by alterations of valves.

No. 26 diagram was taken from the same Engine, on August 23rd, 1856, by the same *Indicator*. Here will be seen a greatly increased power over No. 24 diagram. The average pressure of No. 24 diagram was 17·94lbs; of No. 25 diagram, 21·54; and of No. 26 diagram, 23·97lbs; being in the last case upwards of thirty per cent more power performed by the same Engine. In both the last cases, the strain upon the parts was steady and regular, and the Engine was not nearly so injuriously affected as when the steam was introduced in full force upon the piston by the old method of valve-setting. The valves in No. 24 would by many be considered to be properly set; and had the diagram been taken with a small *Indicator*, such as that made by M'Naught and others, the irregularities would not have been shown, and the valves would in that case have been passed as being correctly set. A state of things like these is too often the case, and forms one of the obstacles to the further

Diagram No. 26.

Taken from the Top of the Cylinder.



Steam, 11·13lbs.

12·84lbs Vacuum.
11·13 Steam.

23·97 Average pressure.

improvement of the Steam Engine. When this defective instrument is relied upon, where one set of valves are found to be as well set as in the instance we are illustrating, two will be found to be worse. With valves set as in the case of No. 26, it would be almost impossible for a break-down to occur from improper action on the part of the Engine itself, as the strain is nearly equal throughout the stroke, and without undue pressure upon the crank.

The benefit of a better knowledge in this important portion of an Engineer's duty is apparent in the increased power in diagrams Nos. 25 and 26, with very little increased cost of fuel, and with a great prevention of strain upon the parts of the Engine, decreasing materially the cost of wear and tear. This case also presents an example of an Engineer who properly understands the use of the *Indicator;* and it makes manifest the advantages to be derived by employers from the use of the instrument in the hands of a man competent to apply it. There are Engineers who know, but who do not like to acknowledge, their former opinions to have been erroneous respecting the improved *Indicator;* and they have in some cases found it convenient to have one of the latter to set valves by, because they have found the facts stated in previous editions of this work to have been of use to them.

In this Engine the valves were of the equilibrium conical form, worked by FAIRBAIRN'S patent vertical revolving tappets. When the valves were altered, hoops were fixed to the inside of the valve, about one and a half inches deep, and of nearly the same diameter as the opening of the valve seat. The mode of working the valves was the same as before

the alteration; but openings, or thoroughfares, were cut in the rim of the hoops of such form and dimensions, that when the valves were raised from their seats, the openings in the hoops allowed the steam to pass in proportion to the distance the valve was raised, by which means the steam was admitted on to the piston at the pressure required, and at any part of the stroke. The steam was also cut off in the same manner. A similar effect may be produced by the tappets being so formed as to raise the valves at any required speed: but the former method is more permanent, and more easily accomplished than the other. Tappets are liable to wear, and to move; but the placing of a hoop inside the valve is not liable to this defect. The plan of the hoop was introduced by the Engineer above referred to; and it will be found to be a step in the right direction—in the practical application of improvements to the valves of Steam Engines. To the equilibrium or the double-cone throttle valves, the hoop has been found to be a valuable improvement, producing steadiness in turning.*

By studying the last three diagrams, those conversant with the improvements therein shewn as having been made in the working of the Engines, and of the increase of real power obtained from the same nominal force, will at once see the advantage of good management over the bombast and guess-work of those who are ignorant of the use of the *Indicator*. Where an Engineer is driving his Engines without using an *Indicator* proper working will be merely the result of chance.

In 1851, Messrs. HYDE, SONS, AND SOWERBY'S

* See Chapter on Throttle Valves.

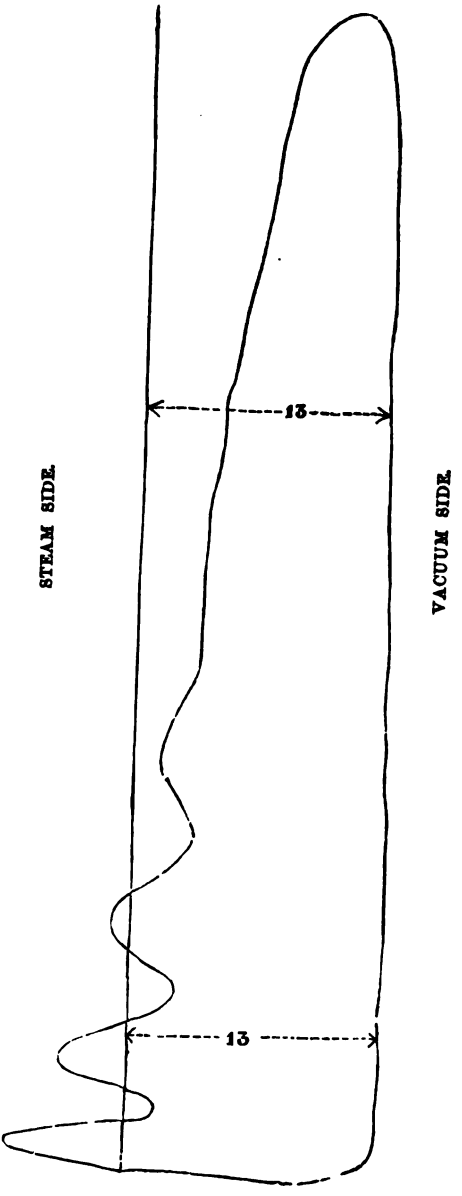
Engines were giving 415 indicated horse-power, and consuming 83¼ tons of coal per week, being 7½lbs of coal per horse-power per hour. This included the steam for the mills, and other purposes requisite in the processes beginning with cotton in its raw state, and delivering it in the woven piece.

In 1860, the same Engines were giving out 670 indicated horse-power, with a consumption of fuel of 94¾ tons per week; that is, under 5¼lbs of coal per hour per horse power: thus showing an increased power of upwards of fifty per cent, obtained from the same Engines, without the least alteration except the proper setting of the valves, and increasing the pressure of the steam from 10lbs to the square inch in 1851, to 30lbs to the square inch in 1860. Since the above date, this consumption of fuel has been further reduced by increasing the pressure in the boilers, casing the cylinders, and using the boiler-pressure in the casings. During the derangement consequent on the short supply of cotton, the mills have not run full time; therefore we are not able to give the exact number of horse-power given out from the quantity of coal used, at the time this edition is in the press

Nothing can be more clear than this case. The facts speak for themselves. Had these Engines been compounded, and the pressure increased in the same ratio, more fuel would have been consumed, to say nothing of the great cost of compounding, and the increase of wear and tear. Instead of this, the Engines only required the usual outlay in repairs. There was no loss of time; and the result was, equally steady turning to that of others whose expenses had been much greater. What can this superiority of

Diagram No. 27.

Taken from the Top of the Cylinder of a Condensing Engine.



management be attributed to? Simply to the proprietors and the Engineer using and understanding the Steam Engine *Indicator;* for without this instrument they would not have been able to increase and regulate their power, but would have been like many—continually guessing as to what the result of various alterations would be.

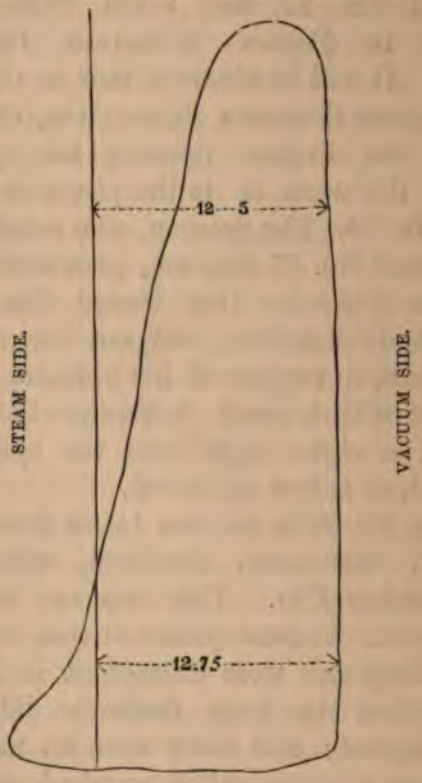
Diagram No. 27 was taken from an Engine belonging to Messrs. MITCHELL BROTHERS, of Bradford. It will be observed that on the steam side of the diagram there is a zig-zag line, caused by the valve of the Engine opening too quickly, and admitting the steam on to the piston as explained in diagram No. 24. The fireman, who acted as Engineer in the case of No. 27 diagram, protested that it was a defective *Indicator* that caused the irregularity thereby made manifest, and not the valves of the Engine; and, in support of his opinion, he indicated the Engine with a small *Indicator*—the pencil projecting at a right angle from the cylinder of the instrument, as before explained.

Diagram No. 28 is the one taken from the Engine of Messrs. MITCHELL, Bradford, with the small *Indicator* referred to. This does not shew the valve to be forward. In consequence of this, the proprietors and their Engineer were immovable in their opinion, and held that the large *Indicator* did not take a correct diagram; and there were no means of convincing them that the valves required more lap, with a V cut on the steam side—as hereafter explained—so as to admit the steam on easily, that when the crank had passed the centre it would be ready to receive the full pressure required without any extra strain on the Engine. This would also have effected

a great saving of fuel, the pressure in the boilers being upwards of 20lbs per square inch. This amount of power ought to have been better applied, by working the steam more expansively. If lap had been added

DIAGRAM No. 28.

Taken from the Top of the Cylinder of a Condensing Engine.



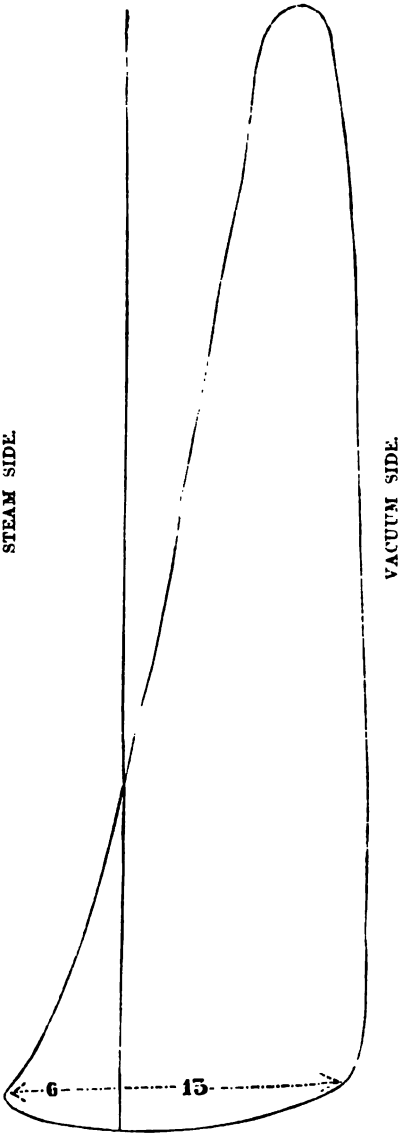
to the valve, instead of wire-drawing the steam through the throttle-valve, and making use of the whole pressure they had in the boiler, much less coal and water would have been used, and more power obtained with less labour and attention.

With the same instrument with which diagram No. 27 was taken, was also taken diagram No. 29, from an Engine belonging to Messrs. ARMITAGE AND KAYE, Huddersfield, to shew the parties at Bradford that where the valves were properly set, no zig-zag line would be made. In this instance the V in the valves, and the setting, are so arranged, that the full force of the steam is exerted on the piston when the crank is in a position to receive it, and not before, as is too frequently the case. The diagram shews by the rounding at the steam corner, that the crank has passed the centre before the full pressure of the steam is applied to the piston. Had the Engine, from which Nos. 27 and 28 diagrams were taken, been more heavily loaded, the jumping motion would have been a serious drawback. In that instance the steam was wasted, for want of being worked more expansively, and the Engine was strained by the valves having too much lead and opening too quickly.

As the difference shewn by the two *Indicators* could not be explained to the satisfaction of the proprietors and manager of the Engine, the diagrams were sent, as they stated, to *a practical man* at the Low Moor Iron Works, for him to examine and report upon: and as his opinion agreed with that of the proprietors and their fireman, it was, of course, settled that the large *Indicator* was at fault. Had it been otherwise, there would have been hope that the old school were about to learn some new lessons. This case is here explained—not that it deserves, or is worthy of, notice in itself—but to show parties who are ignorant of the working of the *Indicator*, and to some extent the working of the Steam Engine, that the *Indicator* is a faithful delineator of the inner

Diagram No. 29.

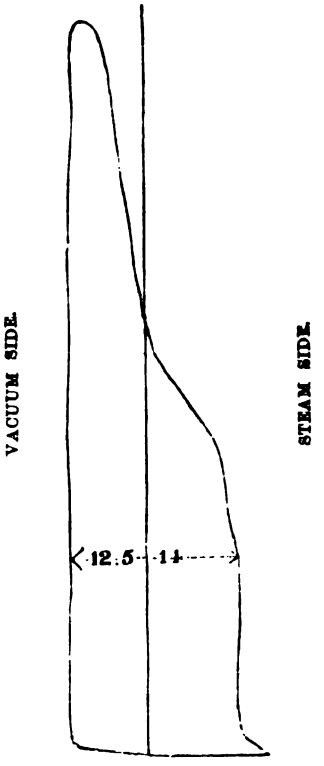
Taken from the Top of the Cylinder of a Condensing Engine.



; of the Engine; and that from improper
ıtting the most disastrous results may be
ıted.

DIAGRAM No. 30.

rom the Bottom of the Cylinder of a Condensing Engine.



ırietors of Steam Engines ought therefore to be
ıs in listening to the opinions of inexperienced
ven in direct opposition to the recorded action
Indicator.

accompanying diagrams, Nos. 30 and 31, afford
ɜe sufficient to convince the most obstinate,

that unless the *Indicator* be one that will faithfully represent the action of the steam upon the piston it is worse than useless.

Diagram No. 30 was taken by a small *Indicator*, from an Engine belonging to Mr. DICKENSON, of Blackburn. The diagram is of the full size. The instrument belonged to the Engine builder. The diagram taken by Mr. DICKENSON'S own *Indicator*, which had the pencil hanging parallel to the piston, was much larger, and shewed the valves to be too forward. As the pressure in the boiler was upwards of 40lbs per square inch, this state of the valves, as shewn by the large instrument, led to an apprehension as to the fate of the Engine, unless the valves were properly set; but the maker contended that inasmuch as his *Indicator* only shewed a small projection on the steam side—as will be observed on reference to the diagram—the valves were right; and he would not condescend to notice any other diagram, or yield to any other opinion. From this obstinacy a contest ensued, in which the Engine-maker had, for a time the advantage. This however was doomed to be very short; for as physical action will produce greater effects in the destruction of an Engine than mere assertions, however wild, the matter was decided within a fortnight by the Engine breaking down. This result had been foreseen and foretold; and had reason been listened to instead of assumption, the proprietor would have been spared the loss, which he did not deserve, for his desire was to have the Engine put right. If the reader will examine diagram No. 30, on the steam side the small projection appears scarcely deserving of notice; for where the instrument is small in construction, and contracted in action, the

proper working of the Engine piston is not accurately shewn. Had these valves been set so as to have made a figure similar to diagram No. 25, there would not have been a break-down even with one-third more work on.

Diagram No. 31 was taken from another Engine belonging to Mr. DICKENSON, of Blackburn, by Mr. DICKENSON's own *Indicator*—the one which had been applied to the Engine which broke down, and which led him to doubt the indications of the small instrument set forth in diagram No. 30. There requires no comment as to the state of this Engine, as shewn by diagram No. 31. Suffice it to say, the Engine-builder again ascribed the fault of the figure as arising from the irregular action of the *Indicator;* and his opinion would no doubt have again passed as correct, had not the same *Indicator* produced diagram No. 32 on the same day at an adjoining mill, belonging to Messrs. LIVSEY AND RODGETT, where the valves were properly set, the Engineer having a knowledge of an Engine and understanding the *Indicator*. No better evidence as to the proper state of the valves and Engine is required than the diagram itself. In this case the condensing water was hot, and therefore there could scarcely be obtained more than a 12lbs vacuum.

Diagram No. 33 was taken from the bottom of the cylinder of an Engine in the neighbourhood of Duckinfield. It will be observed that the steam was admitted to the piston after it had travelled a great portion of the stroke. The vacuum was very imperfect, and the valves were altogether deranged.

Diagram No. 34 was taken from the same Engine, after the valves had been adjusted. The Engine, on being indicated for the first time after the alteration,

Diagram No. 31.

Taken from the Top of the Cylinder of a Condensing Engine.

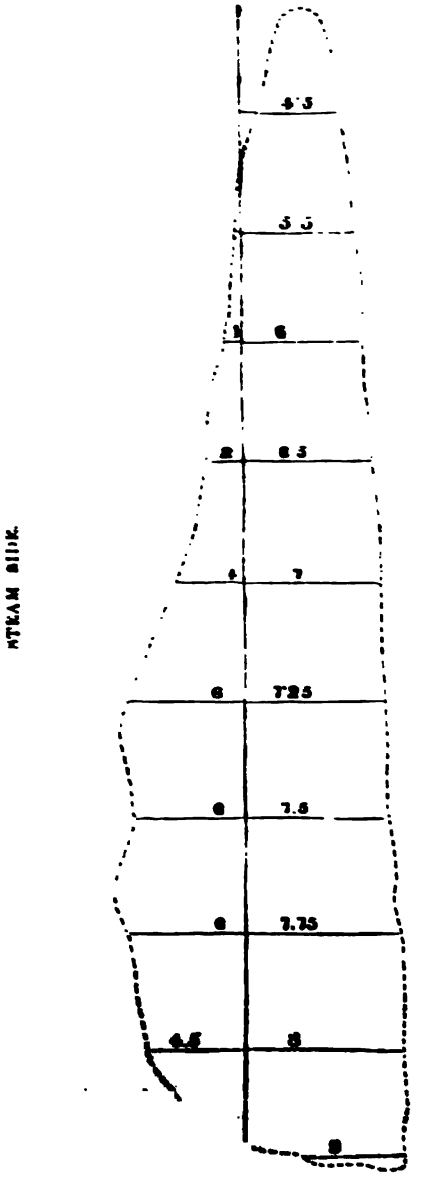


Diagram No. 32.

ken from the Top of the Cylinder of a Condensing Engine

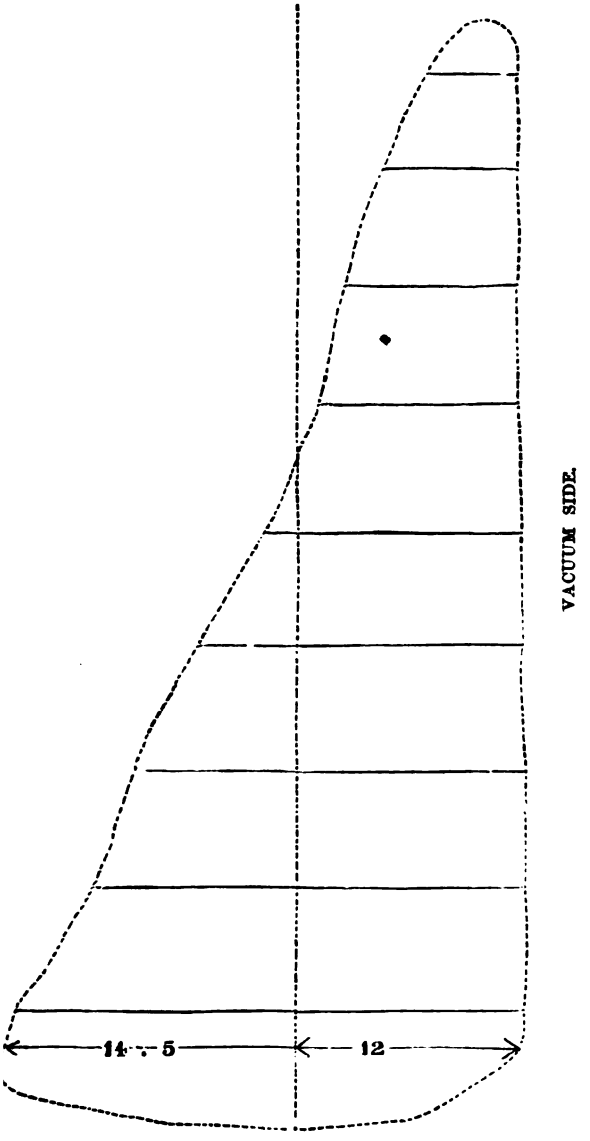


Diagram No. 88.

Taken from the Bottom of the Cylinder of a Condensing Engine.

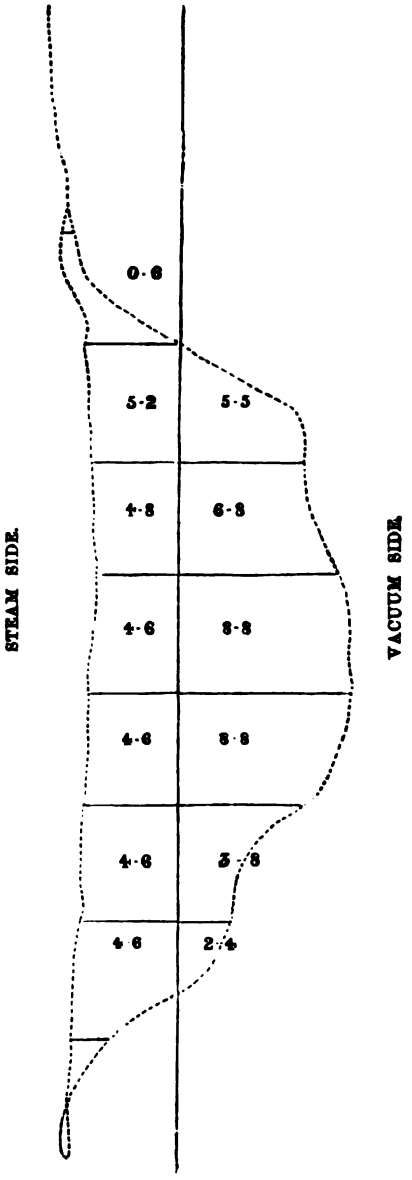
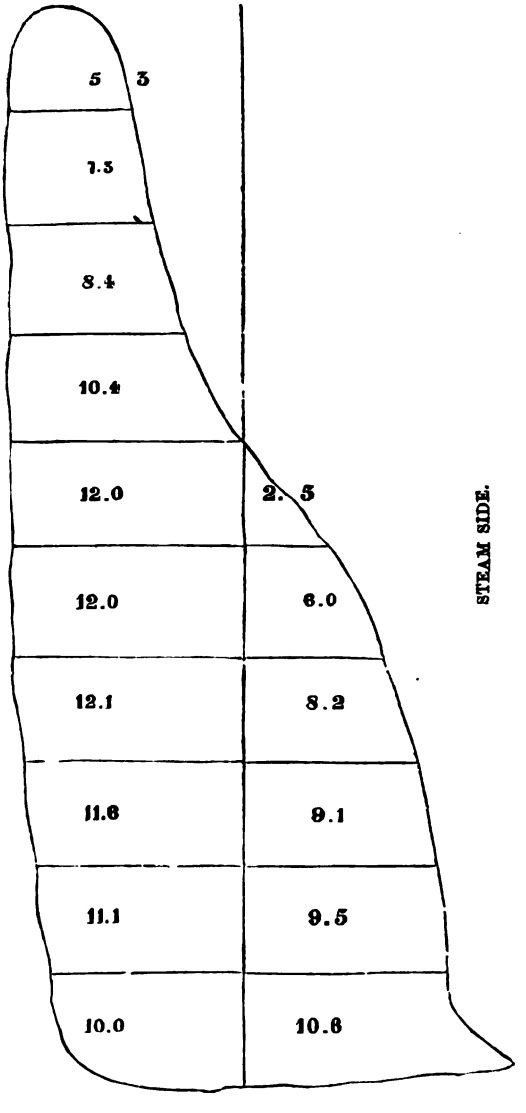


Diagram No. 34.

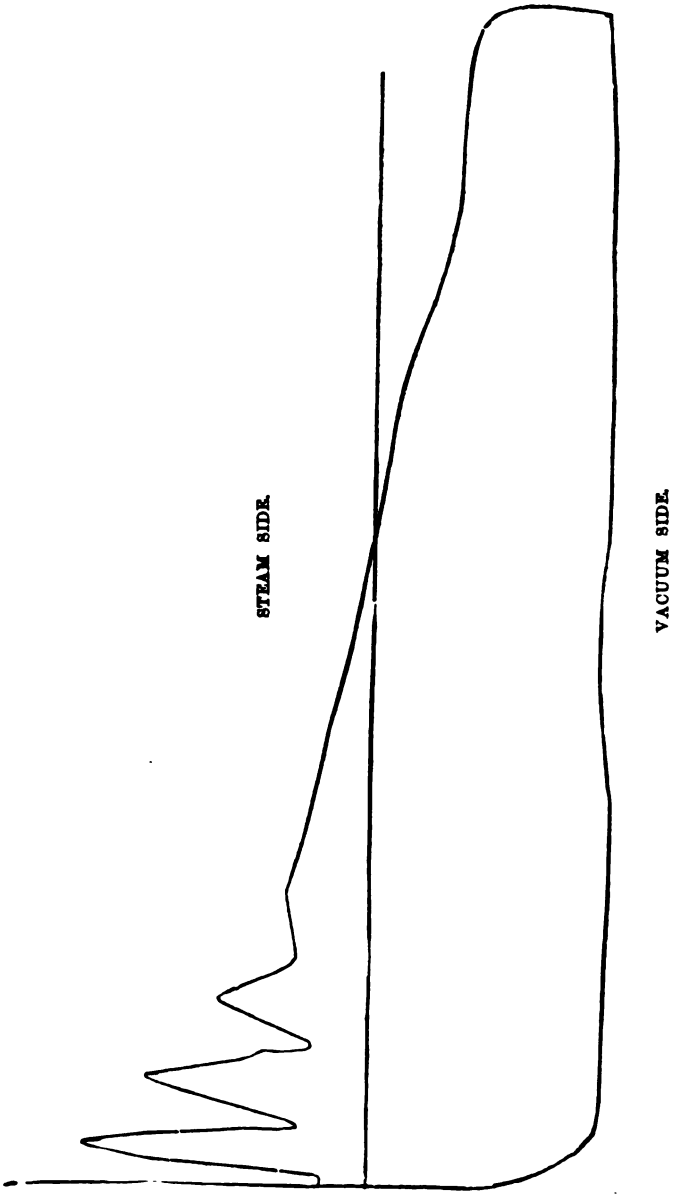
m the Bottom of the Cylinder of a Condensing Engine.



7

Diagram No. 35.

Taken from the Top of the Cylinder of a Condensing Engine.



shewed, by the diagram, that the steam was admitted rather too quickly at the commencement of the stroke, and the vacuum is not so perfect as it ought to be.

These defects, when made apparent by the *Indicator*, were afterwards remedied, and the Engine made to work properly. The facts of this case are explained more in detail in a letter from the Engineer who was called in to adjust these derangements, a copy of which letter is here given :—

"*Duckinfield, Feb.* 22, 1857.

"Mr. HOPKINSON : SIR,

"I was sent for the other day, to examine the state of an Engine. I enclose a copy of the diagrams taken before and after the alteration. When I first got there, the teeth in the driving wheels were flying out, and the hold-down bolts were breaking, while the Engine could not turn half the work. It had been in this state for a week. The valves are of the D construction, worked with Varley's Patent Cams.* The Engineer, fancying all was not right, set to work and altered the Cams, and forgot where they were fixed before he altered them. Consequently he was completely lost. They sent to us, and I went and put them right, ascertaining from the first diagram taken what was amiss.

"I remain, yours truly,

"ENOCH GLEDHILL."

Diagram No. 35 was taken from an Engine belonging to Mr. SAMUEL COOKE, of Mill Bridge. This is another example of improper valve-setting, and of the most frequent cause of Engines breaking down.

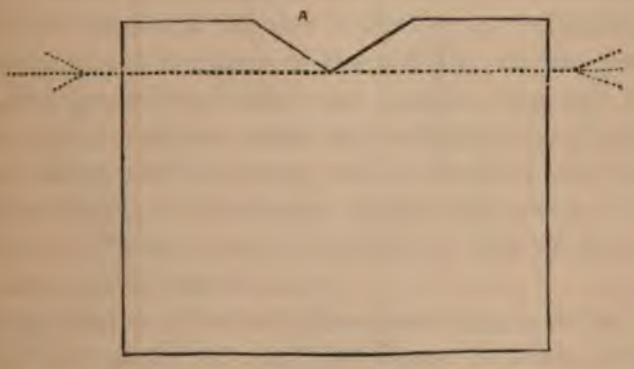
* These Cams are a complicated piece of machinery, and fully prove the want of better information as to the construction and "setting" of Steam Engine valves. The common eccentric motion, with sufficient breadth on the valve face, will regulate the steam to the piston as may be desired, and with much less wear and tear than the patent Cams. In engineering, as well as in some other professions, "sensation" movements take place ; and in no locality has this game been carried to a greater extent than in the town of Bury. Most of them, however, have ended as complicated action generally does—in being found to be "good for nothing."

The pressure of the steam in the boiler, when this diagram was taken, was 30lbs to the square inch. The diameter of the cylinder is 42 inches: the thoroughfares each 20 inches long, and five inches wide. The valves are two short slides. When the crank was at the "plumb centre" the steam side of the valve was one-eighth of an inch open the full width, and the exhaust side two and a half inches open. The pressure of the steam upon the piston, when the crank was at the "plumb centre," was 20lbs per square inch above the atmosphere. When the crank had passed the centre, the steam was reduced down to 5lbs per square inch, which was all the Engine required for the work it had to do; and this amount of pressure ought not to have been exceeded at any time for the amount of power given out, unless the valves had been set to work the steam expansively. As before observed, 20lbs was brought upon the piston; but this 20lbs did not act as steam giving out power to work the machinery, but only as a force to break up the Engine. The great strain thus cast upon the Engine would in time have caused the foundation to give way; and there was every probability that either the beam, the beam centres, or the crank would break. Such occurrences are not unfrequent. When they happen they are often ascribed to anything but the proper cause; and to prevent the recurrence of such disasters, stronger parts to the Engine are substituted as the others are deemed too weak—when, in fact, they were fully strong enough had the valves opened and closed at the proper time, and at a proper speed.

In the case now under consideration, the valves were set and left working without the *Indicator*

having been applied, although the proprietor had one in his possession. The result was, the valves were in the state described. If the proprietor had not known the use and advantage of the *Indicator* better than the Engineers who erected his Engine, in all probability it would have continued in the state as left by them, until it had tumbled to pieces. To remedy the defect, the valves required more lap, and less lead on the steam side. With the size of steam-port provided in this case, the opening would be too large at the beginning. In such a case the required opening can be obtained and regulated by cutting the valve edge in the form of the letter V, as shewn in the annexed engraving.

No. 36.



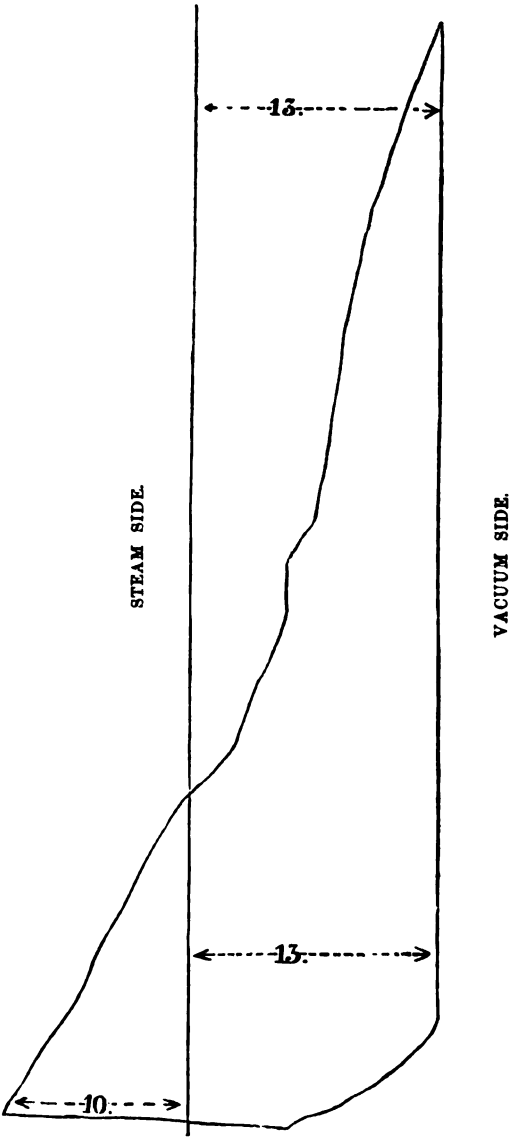
A, the V shaped grove made in the Valve edge.

The V portion is taken out at A, that the steam may be admitted upon the piston gradually; the dotted line shewing the amount of lead (or no lead) on the steam side when the crank is at the plumb centre, before the valve opens to full pressure.

It will at once be seen that as the valve moves

Diagram No. 37.

Taken from the Top of the same Engine Cylinder as No. 35.



forward, the opening gradually increases in size. The crank will have passed the centre before the valve has opened to the whole length of the thoroughfare, or so much as is required; the strain will thereby be taken off the Engine, and the piston and crank will be prepared to receive the full pressure of the steam. By these means the force exerted is properly applied, instead of being expended in a dead lift upon the beam, the centres, and other parts of the Engine itself. By adding more lap to the valve, the steam would be sooner cut off, and more pressure thereby brought upon the piston during the time the valve was open: thus working more expansively, and consequently more economically. This ought to have been the case in the instance under consideration, as there was 30lbs pressure in the boiler. We often find that the pressure in the boiler is no criterion or measure of the pressure in the cylinder, or the power the Engine is exerting; and it often happens that where there are no means of indicating the Engine, great discrepancies arise, and alterations are made without data, or knowledge of the real state of the Engine. These generally result in loss of fuel, in repairs, and in loss of time.

Diagram No. 37 is from the same Engine as No. 35. It will be perceived that the steam expands to the lowest practical quantity, making the most of it, and taking little water to condense with. It will be apparent that the steam is not so soon on the piston, and that the exhaust opens earlier. A very slight alteration made the difference as before explained. The following letter was received with the diagram:—

"*Liversedge, near Leeds, May 29th,* 1861.

"Messrs. Hopkinson & Co:

"Gentlemen,—We have made the alteration (suggested by you Mr. Hopkinson, when last here) on the exhaust side of the valves. Except the wavy line on the steam side, we think we have now a very fair diagram. Enclosed we beg to hand a copy,

"And remain yours respectfully,

"SAMUEL COOKE & SON."

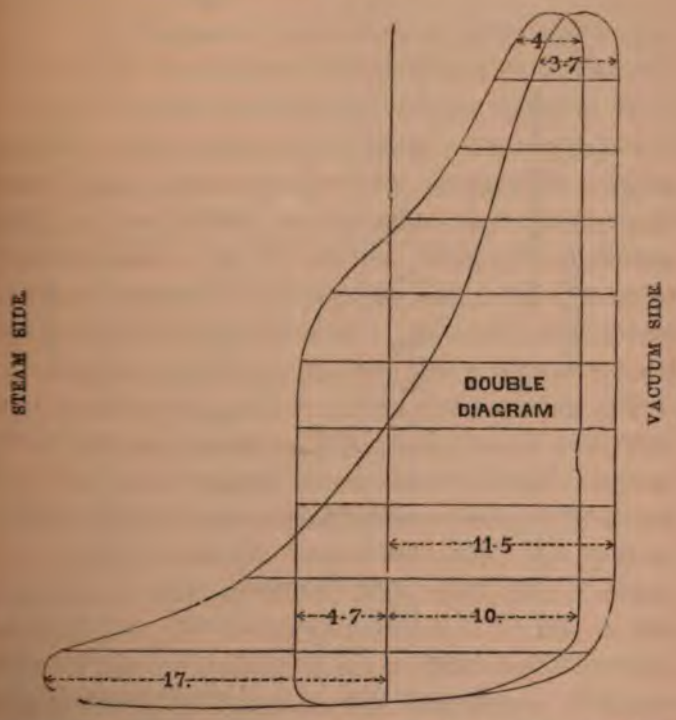
EXAMPLES FROM VARIOUS ENGINES.

Diagram No. 38 is a double diagram, from an Engine belonging to Mr. Leming, of Bradford, Yorkshire. In a dry season, water in Bradford is scarce, and Engines are sometimes unable to work for want of it. The temperature of the condensing water often exceeds 110 degrees Fahrenheit at the time it is required to be used in the condenser.

The low-pressure diagram shews that the valve had sufficient lap to cut off the steam at one half the stroke. The form of the valve was a long slide. The pressure of steam in the boiler was 7lbs to the square inch above atmospheric pressure, and 4·7lbs upon the piston at the commencement of the stroke, and a 10lbs vacuum at the termination. The high-pressure diagram shews the steam to have been at 17lbs on the piston above atmospheric pressure at the commencement of the stroke: cut off at one-tenth of the traverse of the piston, by a revolving expansion valve, described at pages 81 to 84: the steam in the boiler was 25lbs pressure to the square inch above the atmosphere, and an increased vacuum was gained of 1½lbs at the termination of the stroke: the low-

essure being only 10lbs, and the high-pressure -5lbs: thus shewing the advantage of high over low eam, where the condensing water is hot. Even here the water is not hot, the result will be similar. his may be taken as a good example, both with low d high steam, shewing the advantage of proper

DIAGRAM No. 38.

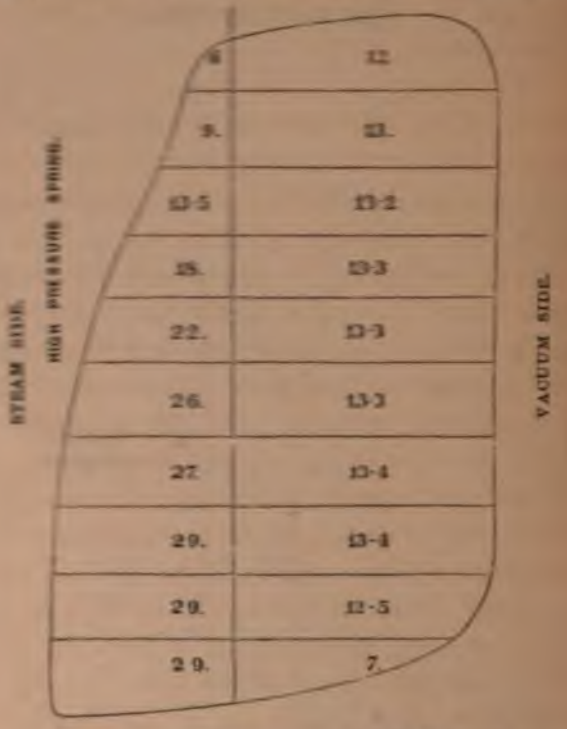


anagement on the part of the Engineer—making e most of his steam according to the pressure. working on the expansive principle, by giving the de valve all the lap possible, after putting in new ilers and a revolving expansion valve, the advantage s apparent. Both fuel and water were saved: the

latter, in such a place as Bradford, being of as much importance as the former. Let these diagrams be compared with some others we have given, and the value of good management will be apparent.

Diagram No. 39.

Taken from the Top of the Cylinder of a Condensing Engine.



Steam 20·8lbs.

12·4lbs Vacuum.
20·8 Steam.

33·2 Average Pressure.

Diagram No. 39 is an example of an Eng having wide steam ways, the exhaust much lead, a the condenser large. It was taken by the *Indica* with the second or high-pressure spring attached.

Here we have an Engine with a vacuum averaging nearly 13lbs to the square inch, with 29lbs pressure of steam at the commencement of the stroke, cut off at one half the length of the cylinder; and at the termination of the stroke there is 6lbs above the atmosphere to condense. This is a proof of room in the side-pipes and the condenser, and also of the valve having much lap and much traverse. The result is an excellent vacuum.

From this diagram it will be seen that at the commencement of the exhaust the vacuum is 12lbs, and it averages, for the whole length of the cylinder, more than 13lbs; thus shewing the great power performed by the Engine, principally from having its valves properly set, and plenty of room in the thoroughfares and condenser. On the steam side the average pressure is upwards of 20lbs; making a total average of steam and vacuum, 33·2lbs. Take off the friction for the Engine and shafting, and the available power is 30lbs to the square inch. The speed of the piston was 350 feet per minute. Compare this Engine with its load to the nominal horse-power Steam Engines are calculated to drive—calculation being 7lbs to the square inch available pressure upon the piston, travelling at the rate of 220 feet per minute. According to WATT's calculation, a 26 inches diameter cylinder will give 24 nominal horse-power; a calculation still followed by Engineers. Suppose the pressure were increased from 7lbs to 30lbs to the square inch, and the speed to 350 feet per minute, as in diagram No. 39, the 24-horse Engine would, providing the parts were strong enough, be working seven times the nominal power the Engine was calculated for, with a proportionately less consumption of

coal and water for the work done: a matter of consideration to proprietors of Steam Engines. Many Engines, however, are prevented from working up to the power they could be worked at, for want of room in the valve-box for the necessary traverse, and from having a crippled condenser. Where Cornish and equilibrium drop-valves are used, the fault of the valve-box being too short is compensated for; but in far too many cases the thoroughfares are too contracted. There ought to be no practical difficulty in the way of having steam ways and valves made sufficiently large. A great advantage arises therefrom, when the Engine becomes loaded; and at all times this construction produces a saving of fuel, by giving the steam free access to the piston, and free egress to the condenser or to the atmosphere, as the case may be. When the steam in the boiler is of sufficient pressure, and the pipes and thoroughfares small, the deficiency is often in the exhaust passages, whether the Engine be a high or a low pressure one. The steam in such case is not used up, because the load on the Engine is too great; consequently the steam has to be kept on the piston at the expense of fuel, and very little expansion can be obtained.

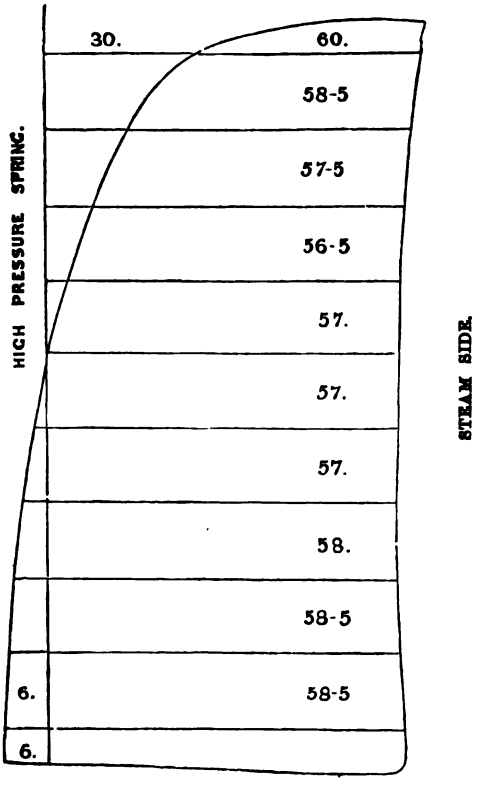
No. 40 diagram, and also No. 41, were taken from a double-cylinder Engine, in Stockport, constructed upon HORNBLOWER's principle.

No. 40 was taken from the bottom of the high-pressure cylinder, and No. 41 from the top of the low-pressure cylinder; the steam first operating in a small high-pressure cylinder, and then expanding in a large condensing cylinder. The steam in the boiler was 66lbs to the square inch above the atmosphere. Diagram No. 40 shews a vacuum of 6lbs in the high-

sure cylinder on the exhaust side, which is the lt of the pressure on the steam side expanding w the atmospheric pressure; and it also shews the Engine was making an excellent vacuum in condensing cylinder, as shewn by diagram No. 41.

Diagram No. 40.

Taken from the Bottom of the High-pressure Cylinder.

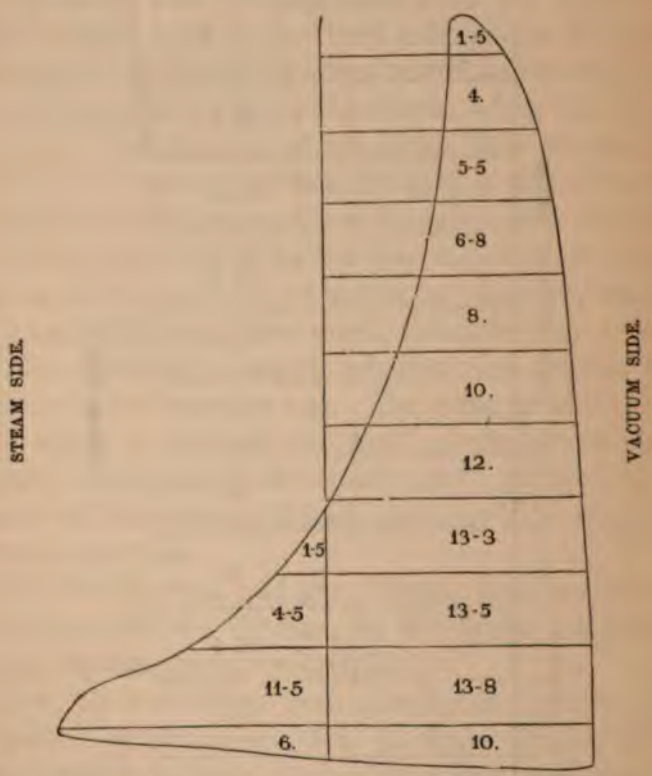


e exhaust-valve opens too late and closes too late. e power of these two Engines, of two cylinders ch, united, is 960 horse, as shewn by the *Indicator*.

The consumption of fuel was 3½lbs per hour per horse power. In these Engines the principles of WOLFE and HORNBLOWER are well carried out—viz.: expansion of steam by means of two cylinders, and the steam at high-pressure, with WOLFE's boilers. It is now more

DIAGRAM No. 41.

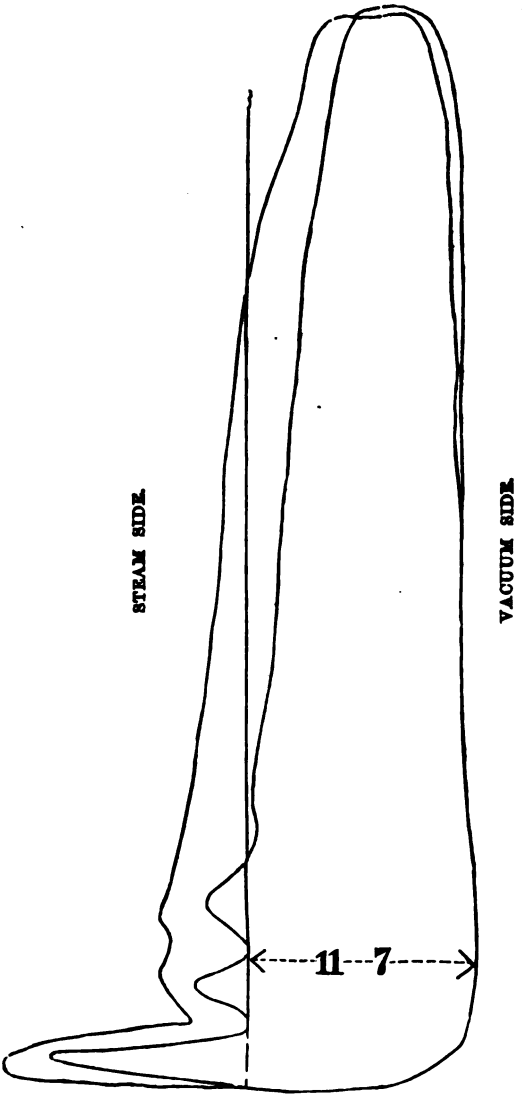
Taken from the Top of the Low-pressure Cylinder.



than sixty years since these principles were laid down and partially carried into practice. Up to the present time they have not made much progress. This is to be attributed to the great prejudice in favour of old

Diagram No. 42.

from the Top of the Cylinder of a Condensing Engine.



constructions and old modes of practice, which had to be overcome. Nothing has so much tended to remove the prejudice existing in the minds of Engineers against these principles of true economy of power, as the use of the *Indicator;* for that instrument has made apparent the real facts as to the power and the relative working cost of all descriptions of Engines; and has thus become an unerring test of the pretensions put forth in support of any particular construction, speedily shewing whether these are founded only on conjecture, or whether they have fact for a basis.

Diagram No. 42 was taken on the 13th January, 1859, from an Engine belonging to Messrs. OLDROYD AND SONS, Dewsbury. The diagram shews the steam on the piston for nearly the full length of the stroke. The D valve had little cover or lap, with the edge square, or straight across; so that when the valve opened at the commencement of the stroke, it opened too quickly, admitting too much steam upon the piston before the crank was in a proper position to receive it. In this case a singular coincidence occurred during the time the author was taking the diagram and explaining to the Engineer the cause of the irregularity of the working, and the injurious effects arising from valves set as described. The two lines on the diagram are produced by the throttle valve being too large, opening too much at first, and admitting too much steam, causing the Engine to start and jump, and throw out the governor-balls to their utmost extent. By this action of the governor the valve was closed too much, checking the speed of the Engine, which occurred about every three strokes, and then there was immediately an extra start off again. Whilst the author was explaining these

defects, and the cause of them, a break-down occurred to a pair of driving-wheels. This ought not to have caused surprise, as it was only a natural result from the improper setting of the D valves and the faultiness of the throttle-valve.

Were Engineers to mind this particular point in the setting of their valves, and also see to the proper size of the throttle-valve, which ought to vary according to the pressure of steam in the boiler, their Engines, wheels, and shafting would last much longer, and cost less in repairs.

The Engineer in this case could not agree with the report, as established by the diagram, that his Engine valves were improperly set—"because," as he said, "he had had great practice with Engines." He would not accept the facts pointed out by the *Indicator*, because of that most silly of all reasons—long habit in a certain rule and routine. We have learned since, however, that the valves of this Engine have been altered and improved.

The following letter, with diagram No. 43, was received from the Engineer whose name it bears :—

"*Buttershaw Mills, May* 28*th*, 1862.

"Messrs. J. Hopkinson & Co., Engineers, Huddersfield.

"Gentlemen,—Will you be so kind as to give me your opinion as to what is the cause of the enclosed diagram being so irregular ?

"I was asked by a friend of mine to indicate one of his Engines, and the following is the result. Mr. Marchant, the maker, does not believe this diagram to be correct.

"I have tried the high-pressure spring, and there is the same result. I may also add that I can take a clear and steady diagram from off our Engines at Messrs. S. Bottomley and Bros., Buttershaw Mills, North Bierley, with the same *Indicator*. The *Indicator* is one of your make.

"Please reply by next post if you possibly can.

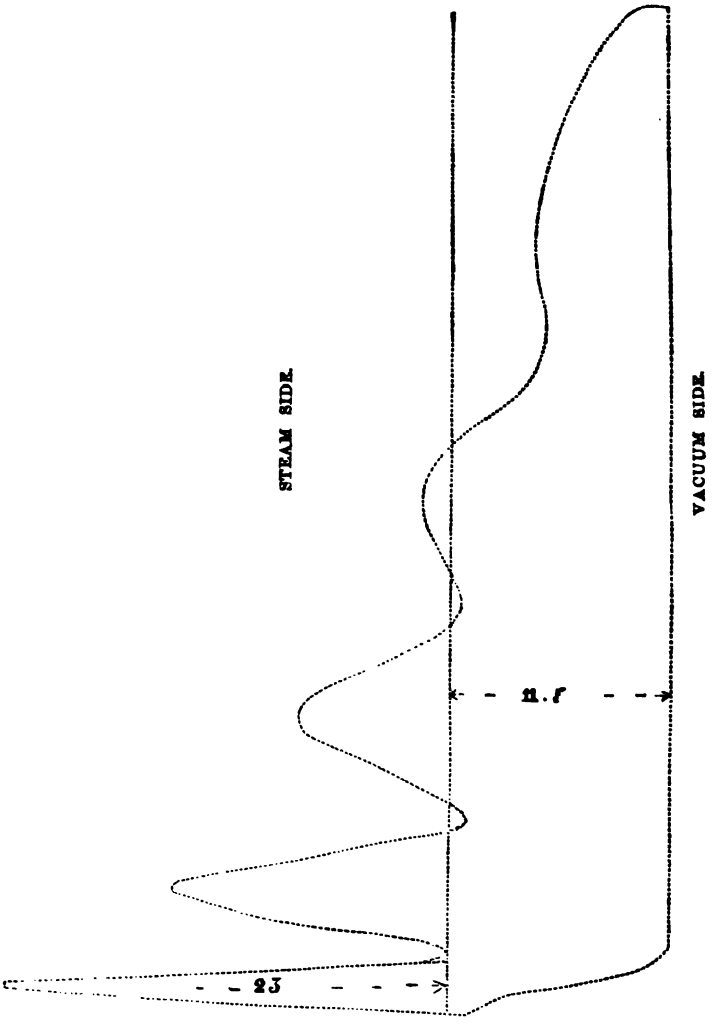
"Yours, &c.,

"WILLIAM KELLETT."

The diagram shows that the steam is too early at the beginning of the stroke; and when the valve opens, the opening at the commencement is too large,

DIAGRAM No. 43.

Taken from the Top of the Cylinder.



admits the steam too fast, causing the *Indicator* piston to rebound, and thus giving to the diagram an irregular line on the steam side. 23lbs pressure is brought upon the piston when the crank is at plumb centre. Less than one-half of that pressure would be more than required when the crank was in a position to receive it if the valve had less lead and less opening at the beginning. There is no wonder that Steam Engines are broken down where valves are set as shewn by this diagram. Were Engine builders to use the *Indicator* more, and study its diagrams, they would soon discover many things to their own advantage, and that of the proprietors of Steam Engines.

In the case before us, had the Engine maker believed less, and ascertained more of the fact, what a difference he would have made to the working of the Engine by properly setting the valves. But, relying on his "belief," the Engine will continue to work until it tumbles down, which will assuredly take place, if not altered. When broken down, there probably will be the old excuse: "she has been too heavily loaded," or "the kind of work she has had to do would break the best Engine ever made." We are glad to learn that Engine-men are evidencing increased interest in the management of the Steam Engine. Formerly, they were content to take the opinion of the builder when anything went wrong; but since the use of the *Indicator* has become more general, the Engine-men are taking their proper place, and teaching the builders of Engines practical facts connected with the Steam Engine worthy of their attention. In the case before us, the *Indicator* pointed out that there was a reason for the diagrams

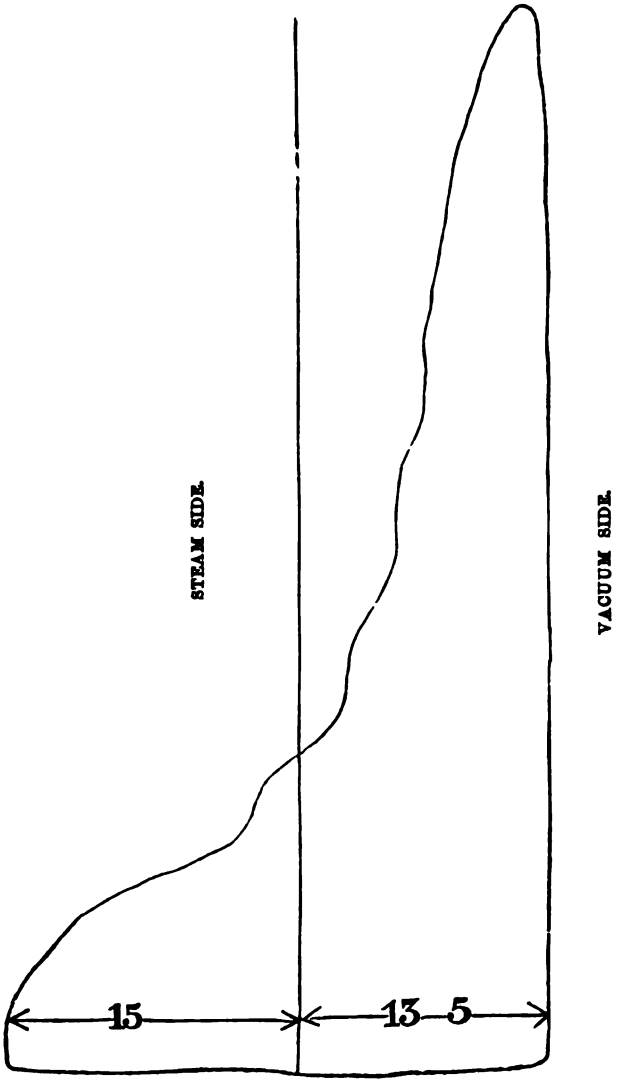
from the two Engines being different,—the one steady, and the other irregular. From such observation, knowledge is gained, and society benefited by examination and discussion.

Diagram No. [illegible] is from one of four Engines belonging to Messrs. Titus Salt and Sons, Saltaire, near Bradford, Yorkshire. The Engines were made by Messrs. Wm. Fairbairn and Sons, of Manchester. The cylinders are each 50 inches diameter, working [illegible] strokes per minute, and 7 feet stroke; the piston travelling [illegible] feet per minute. The cylinder valves are equilibrium drop valves, worked by Fairbairn's patent vertical revolving tappets. The pressure of steam in the boiler was 30lbs per square inch above atmosphere. These Engines are of first-class workmanship, and highly finished. To those who are pleased with mechanical excellence, order, and arrangement, they are well worth going a great distance to see. The perfection at which mechanism has arrived in England, is here conspicuous. The proprietors are noted for their liberality in allowing strangers a sight of the works, which are in themselves a monument of England's greatness, and a rare specimen of what skill and industry can accomplish.

The Engineer who has the charge of the Engines, is one of those who desire and encourage improvement. By his own unflagging energy and industry he has risen to the position he now occupies in the Engineering world. The use of the *Indicator* has been to him a favourite study; and through its teachings he has been enabled to effect great and practical improvement in the working of his Engines. Instead of being wedded to the idea, as are a large number of Engineers, that a small *Indicator* is the

Diagram No. 44.

Taken from the Top of the Cylinder of a Condensing Engine.



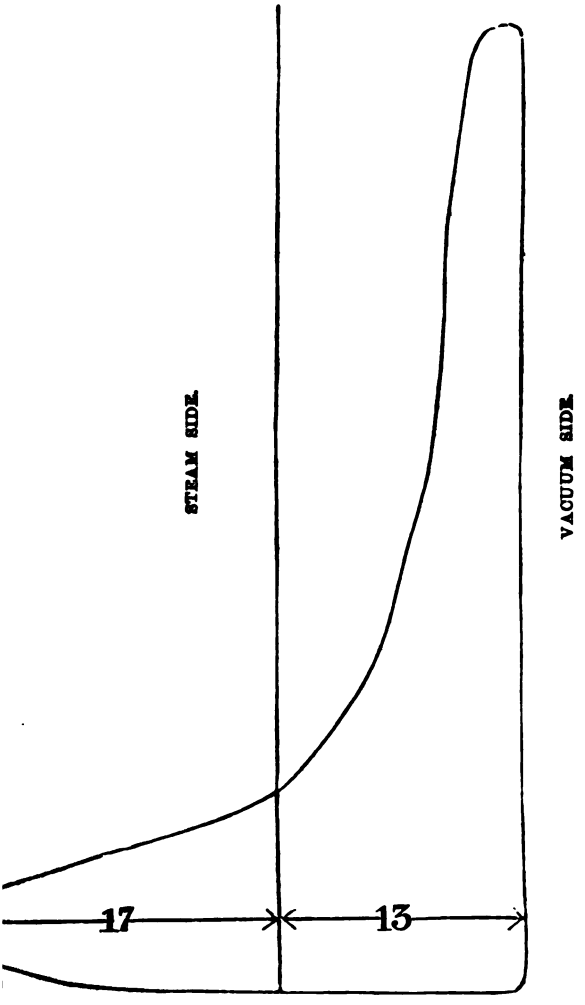
best, he prefers, and has had specially made, a very large one, with which he indicates the working of his Engines—practice having proved to him that the smaller instruments are not sufficiently sensitive in their registration of the real working of Engines. The diagram here given was not taken by the large *Indicator*, but by one of the usual size, made by Messrs. HOPKINSON. It will be perceived that the vacuum is equal from the beginning to the end of the stroke; the steam is cut off early, thus allowing it to expand 10lbs below the atmosphere, leaving very little to condense at the termination of the stroke. Thus the steam is used up to its last practical impelling force—a proof of most excellent work, resulting from skill and knowledge.

Diagram No. 45 was taken from one of a pair of Beam-Engines belonging to Messrs. JOHN SHAW AND SONS, of Stainland. These works are situate betwixt Huddersfield and Halifax, and, as a woollen manufactory, are not surpassed for substance, arrangement, and order. The Engines were made by Messrs. JOHN WOOD AND Co., Lock Hill Foundry, Sowerby Bridge. The cylinders are 37 inches diameter, with 6 feet stroke, the piston making 26½ strokes per minute, travelling at the rate of 318 feet per minute. The expansion of the steam is regulated by the governor; so that in proportion to the work and the pressure in the boiler, the expansion is increased or diminished. When the work on the Engine varies, the governor causes the valves of the cylinder to be moved partially round, and *vice versa;* thus cutting off the steam earlier, or keeping it on the piston longer, by the position of the diagonal thoroughfares in the valves —these being of the form known as piston valves.

ngines work night and day, and therefore
tle time for examination and repairs. The
a the boiler when the diagram was taken

DIAGRAM No. 45.

om the Top of the Cylinder of a Condensing Engine.



was 30lbs to the square inch above the atmosphere. Since that time new boilers have been put down, and the pressure increased. According to the diagram, 17lbs per square inch was brought upon the piston at the commencement of the stroke, that pressure being admitted in a proper and easy manner. The steam was cut off after a very short traverse of the piston, expanding down to a very low temperature at the termination of the stroke, making an average vacuum throughout of 13lbs per square inch.

It will be seen that in this and the last case, the Engines were not over-loaded—thus enabling them to use up the steam to the furthest practical limit. In both cases, the average consumption of coal of inferior quality was 3lbs per horse power per hour. Had these Engines double their present amount of work to perform, the consumption of fuel would be greater in proportion to the power obtained, because the steam at the termination of the stroke would be proportionately at a greater pressure, and would have to be condensed before it had expanded to its extreme limit, and would only realise the same amount of vacuum.

Such a pair of Engines and Engine-house as are to be seen at the works of the Messrs. SHAW are unsurpassed in the kingdom, either for appearance, cleanliness, or attention. The Engineer, Mr. ROBINSON, has them in such order that those who see them —and many go on purpose—have a treat of no ordinary kind.

Here also the *Indicator* has been at work—the Engineer by his skill and knowledge of a diagram when taken, having been able to accomplish improvements in the working of his Engines, until he has

realized what is shewn by the diagram. Many others, similarly situate, are using nearly double the quantity of fuel for the same amount of work done—simply because they prefer managing by "rule of thumb," or as a sage once observed, they "grope their way."

The last two examples of Steam Engines are nearly equal, for use, beauty, and good management. The Engineers in both cases owe their present position to having early instructed themselves in the use and advantage of the Steam Engine *Indicator;* and the results they have attained afford an example which, if followed by others, would be of lasting benefit to themselves and their employers.

Diagram No. 46 accompanied a copy of a Report sent to Mr. W. H. Aston, Zetland Mills, Huddersfield, from the "*Huddersfield District Association for the Prevention of Steam Boiler Explosions, and for effecting economy in the raising and use of Steam.*"

REPORT.

"Boiler Shell in working condition.
"Safety Valve in working condition, and blowing off at 30lbs.
"Pressure per Steam guage, 34lbs per square inch.
"Pressure per *Indicator* 34lbs do.
"Temperature of Injection Water, 50 degrees.
"In Hot-well .. ... 82 do.

"This Engine and Boilers, with their appendages, are in working condition. The inclosed diagram shews that the Engine is equal to 32-horse power. The efficiency of the Engine would be increased by opening the eduction ports a little earlier, and I should be happy to give instruction relating thereto.

"JNO. RHODES, Inspector."

If the reader will examine the diagram, he will observe it presents a great difference to the two preceding diagrams, both in size and form—this

diagram being the full size taken by the Inspector's *Indicator*. In all three cases there was a similar pressure of steam in the boiler, viz: 30lbs per square inch above atmosphere. Yet in the case reported on by the "Huddersfield Association," the steam was

DIAGRAM No. 46.

Taken from the Top of the Cylinder of a Condensing Engine.

introduced to the piston 1lb below atmosphere, and there was steam to condense at the end of the stroke 6lbs below atmosphere. The condensing water was at 50 degrees temperature, though only producing an

11lbs vacuum. Yet the Inspector declares the Engine to be "in working condition," and only suggests that the eduction ports require opening a little earlier."

There requires little or no comment on this report. The exposure of the lines recorded by the *Indicator* tell their own story. But as this report was from a Society which attempted to instruct and improve the minds of Engineers by reporting upon their defects, perhaps it may not be out of place to shew what little dependence can be placed on such examinations. Were this the only instance of the inefficiency of such examinations, it might be overlooked; but as there are many others of a similar class, it is important that the public and the members of such Associations should be acquainted with the real facts of the case.

In the first place, then, when alluding to the boiler, the Inspector reports the safety-valve to be in working condition, blowing off at 30lbs per square inch; and then he immediately says, "pressure per steam guage, 34lbs; pressure per *Indicator*, 34lbs." How could there be 34lbs pressure in the boiler, when the safety-valve is reported as blowing off at 30lbs? That, however, is not of very much importance. The diagram is much more important, and to that, therefore, we refer. The diagram shews that the valves required more lap, and the eccentric putting forward, whereby the steam would be cut off earlier; the exhaust should also be opened and closed earlier, giving a greater pressure at the commencement of the stroke, and less at the termination; thus using less steam, and requiring less water for the purpose of condensation. The vacuum is only 11lbs per square inch—the consequence either of steam passing the

piston and valves, or from a deficiency in the joints, the pump, or parts, admitting air, and destroying the vacuum to the extent of at least 2lbs; thus requiring more water to condense with, and unnecessarily loading the air-pump.

What is there to prevent this Engine from making a similar diagram to the Engines belonging to Messrs. JOHN SHAW AND SONS, TITUS SALT AND SONS, or other parties set forth in this explanation of diagrams? The Engine in this case was consuming considerably more fuel than in the two cases specifically referred to. Still it was reported upon by the Inspector, as being "in working condition." Such a report would not have passed muster with the two firms just named, as the parties to whom it would have been submitted would soon have notified to the Association that an extended knowledge of both Engine and instrument was requisite, before reporting what was necessary to be done to put the Engine in proper working condition.

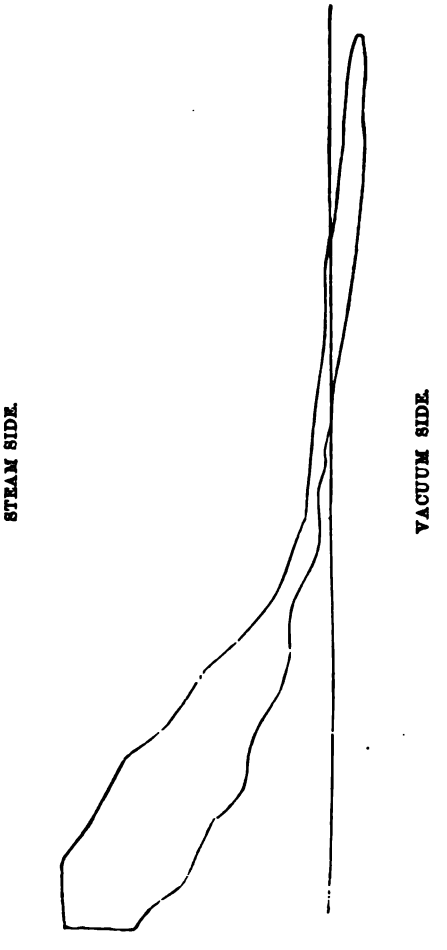
In the working of some of these societies, there is too much officialism and mystification of simple defects. It would be much better were plain and practical instructions vouchsafed to the Engineers, instead of a system of inspection that incites to the idea of "safety," when in reality the reports are generally framed upon information given by those reported upon.

Since the third edition of this work was published, the society above referred to has ceased to exist. The incompetency of its officers to teach others was frequently made manifest while it was in existence; and its committee of management was equally unskilful. Men were placed upon that committee

ıre on account of their position and wealth than for
ɣ practical knowlege they had acquired on the
ɔject of Steam Engines and Steam Boilers.
Diagram No. 47 was taken from one of the Engines
onging to Mr. H. B. TAYLOR, Huddersfield. The

DIAGRAM No. 47.

Taken from the Top of the Cylinder of a Condensing Engine.



steam is only partly on the piston, and no vacuum is formed. The Engine run, but could not do its work. To all appearance there was no particular part deranged. The Engineer obtained an *Indicator* and applied it. This shewed the defect to be in the valves. The inside connecting rod of the D valve was found to be broken; the top valve, therefore, remained stationary, though the bottom valve worked as usual. The defect was soon repaired, and the Engine again at work. Had this case been in the hands of an Engineer who did not understand the use of the *Indicator*, this simple derangement might have cost the proprietor much money and loss of time.

In a case at Messrs. LOCKWOOD AND KEIGHLEY'S, Huddersfield, where they have a forty-horse Condensing Engine, with D valves, an alteration of the Engine was made. New side pipes and two short slides were applied, the Engine speeded, and a new monster boiler put down. Six weeks' time was occupied in making the alteration, and more than £1000 spent. When again at work, it was found that the short slides, with the boiler pressure upon them, required a much greater amount of power to move them than the former valves. The first disaster was the breaking of the rock-shaft, entailing another stoppage. The next discovery was, that for the same amount of power given out, nearly twenty tons of coal per week were consumed more than before the alteration. The new monster boiler was of large dimensions—a "monster" more in name than in reality, as a steam generator. It was of a great length, and was looked upon to be powerful in proportion to that length; a mistake found out long ago by those who have paid attention to the subject of steam generating.

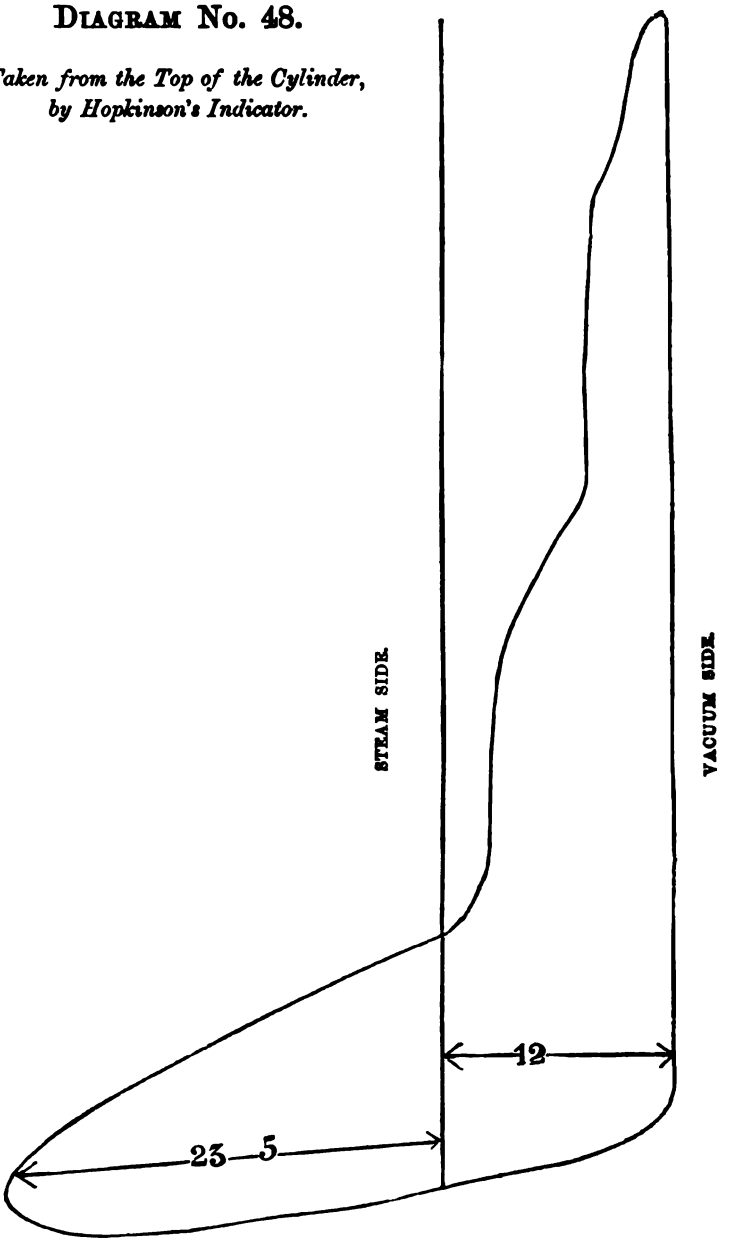
After all this expense had been gone to, time lost, and the old D valves and side pipes melted up, although they were in capital order, a third party had to be called in to restore the Engine to its original form, except the speeding. The side pipes with the short slide-valves were removed, and fresh side pipes affixed, with D valves. This second alteration entailed another stoppage before regularity could be obtained, and the consumption of coal reduced to its former standard. That such cases do occur need not be wondered at, when we find parties professing to be Engineers and Engine-builders ignorant of the use of the *Indicator*.

No. 48 diagram is from a pair of Direct Acting Vertical Steam Engines belonging to Mr. CHEETHAM, Crab Tree Mills, Oldham. They were made by Messrs. WOLSTENHOLME AND RYE, Engineers, Oldham. The cylinders are 22 inches diameter, with four feet stroke, making 47 revolutions per minute, the piston travelling 376 feet per minute. This is good speed for a four feet stroke. The Engines were turning 150 indicated horse power, and only consuming 2¼lbs of inferior coal per hour per horse power. Were the coal of good quality, there would not be used more than 2¼lbs. The pressure of the steam in the boiler was 36lbs above atmosphere. On examining the diagram, it will be observed that the steam was brought upon the piston at the commencement of the stroke at 23·5lbs, and cut off at about a seventh the length of the cylinder, the remainder of the stroke being worked by expansion to 10lbs below the atmosphere, making a 12lbs average vacuum, with warm water to condense with.

This diagram will, to many, appear singular when

Diagram No. 48.

Taken from the Top of the Cylinder, by Hopkinson's Indicator.



it is stated that the valves are of the ordinary D construction, and worked with the common eccentric; proving that the D valve, with the ordinary arrangements, can be made to cut off the steam at any portion of the stroke, where the thoroughfares and valve-boxes are properly constructed. This case is also an example of steam being used up, by being brought upon the piston at the highest pressure, and parted with at the lowest possible pressure.

The direct acting principle is here proved to be the true one. Had there been a couple of heavy beams to swing about, at the speed attained by the construction adopted, the consumption of fuel would have been greater. It should always be borne in mind that a heavy mass of matter cannot be started from a state of rest to a speed of nearly a hundred oscillations per minute, without the consumption of a great amount of power. There still exists a prejudice in favour of Beam Engines; but the time will come when they will be spoken of as amongst the things that were. The old assertion that the D valve cannot be made to cut off the steam at less than half-stroke, is here completely refuted; and parties who have adopted complicated apparatus for working valves, may bid adieu to antiquated notions, and rest assured that simpler principles and adaptations will ultimately succeed. In the locality of Bury there appears to be a sort of mania for *cut-off motions* and *cams* to Steam Engines, which proves the want of a knowledge of first principles, and this too amongst parties whose experience ought long since to have taught them that the simpler the construction of the parts of a Steam Engine, the longer those parts will wear, and the better they will work.

Diagram No. 48 is a specimen of the true working of an *Indicator*. The Engine was making 47 revolutions per minute, without the slightest "trembling" —proving that the valves were well set. This case shews that the *Indicator* only makes "jumping" and "zig-zag" diagrams when the valves are badly set.

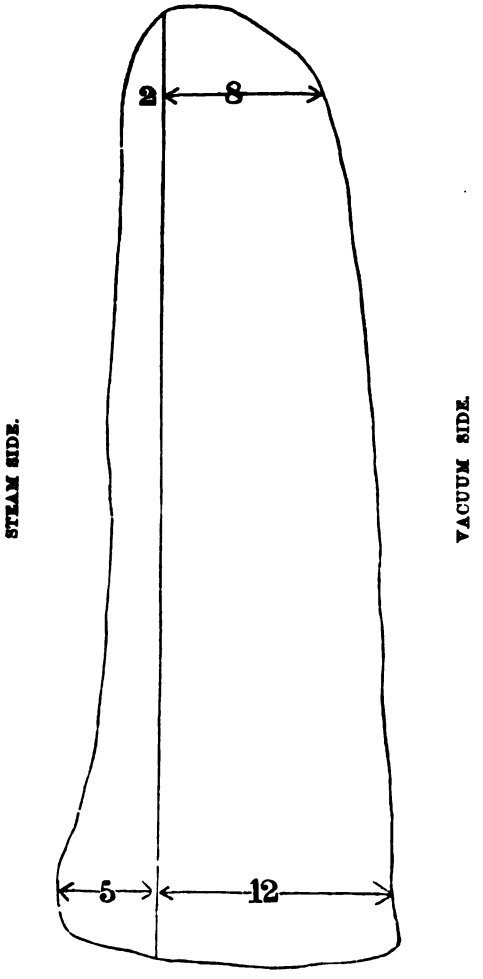
Diagram No. 49 is from a Beam Engine belonging to Mr. ABRAHAM BRIERLEY, Spa Mill, Lepton, near Huddersfield. It is an illustration quite opposite in character to that of Mr. CHEETHAM's (see diagram No. 48), whose Engine is made to use up the steam to the last impelling point, whilst this is using the utmost steam possible, and consuming more than three times the quantity of fuel that ought to be consumed for the work performed. Considering that there was 30lbs pressure of steam in the boiler above atmosphere, which ought to have been made available, we cannot but attribute the glaring mistake which has been here committed, to the want of a knowledge of the properties of steam.

In this case the owner suffers a heavy loss from extra expenditure in fuel; and, what is still worse, no improvement can be made by "lapping" the valves. The valve-box is too short to allow of extra "lap," or traverse. The best course to take with this Engine would be to dispense with the present side pipes and valves, and replace them with the ordinary D, or double-beat Cornish valves, so set, that the pressure in the boiler could be made available, and expanded to the proper limit, before leaving the cylinder. Much less water would be required to condense with, less power to work the air-pump, and there would be less wear and tear in the different parts of the Engine and boiler. At page 60 the "bitting" of thorough-

ı is fully explained, so as to enable the valve to ɔff the steam early. In this case, that mode has . resorted to as a temporary relief, since diagram 49 was taken. The result has been a great saving

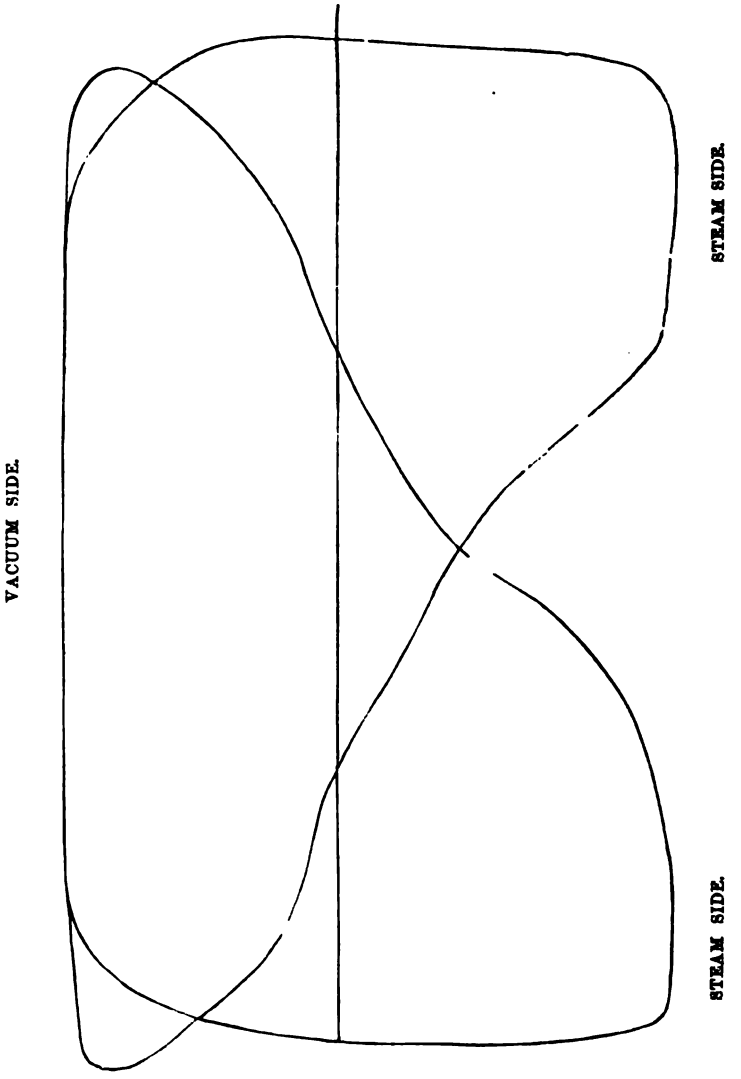
DIAGRAM No. 49.

'aken from the Top of the Cylinder of a Condensing Engine, with a Three-port Valve.



Double Diagram—No. 50.

Taken from the Top and Bottom of the Cylinder of a Condensing Engine, with D *Valves.*



of fuel, and the Engine working better. Were the Engine heavily loaded, the thoroughfares would be found too small, unless the exhaust had a great amount of lead, so as to get out the steam early; and this would be a loss in proportion to the extra lead.

The double diagram, No. 50, was taken from one of the Engines belonging to Messrs. HYDE, SONS, AND SOWERBY, of Duckinfield, and is presented as an example of even valve-setting. It shews that the steam and vacuum on both sides of the piston were alike, and that the Engine was working steadily.

An Engineer, when indicating his Engine, to ascertain its real state should take a double diagram, by which means he will see the slightest difference that may exist in the working, from the admission of steam to the upper and the under side of the piston. A double diagram can be taken with greater ease than adjusting a second paper for a second diagram, as it only requires that the one paper should remain on the barrel untouched, until a diagram is taken from each end of the cylinder. If the parts of the Engine be properly balanced—which they ought to be where steady turning is required—it is essential to indicate both sides of the piston. With valves evenly set, and the parts of the Engine well balanced, less wear and tear will be the result than where these points are not attended to.

Diagram No. 51 was taken from one of a pair of high-pressure cylinders, compounded, belonging to Messrs. GEO. ANDREWS AND SONS, Compstall Mills, near Stockport; and diagram No. 52 was taken from the condensing cylinder, into which the steam from the two high-pressure cylinders exhausts.

The diameter of the high-pressure cylinder is 12⅝ inches, length of stroke 24 inches, making 72 strokes

Diagram No. 51.

Taken from the Top of one of a pair of High-pressure Cylinders of a Compound Engine, exhausting into a Low-pressure Cylinder.

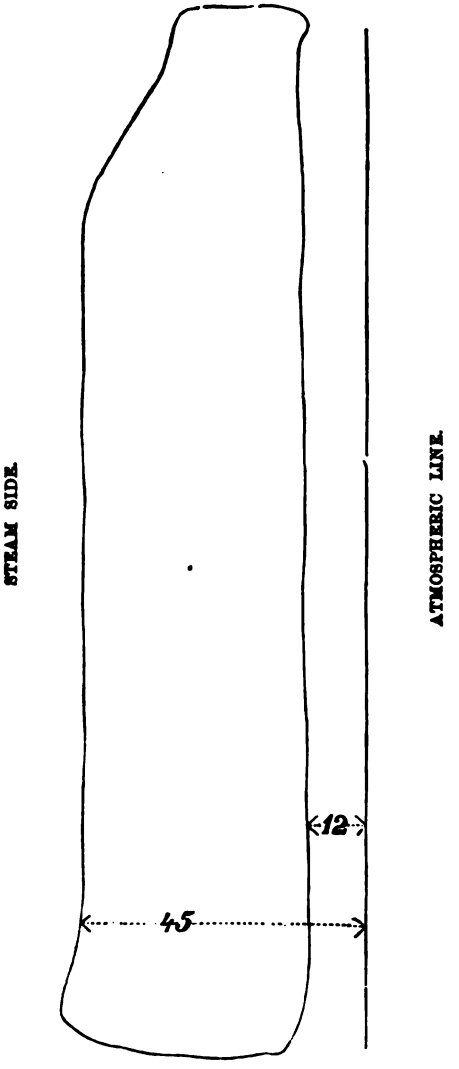
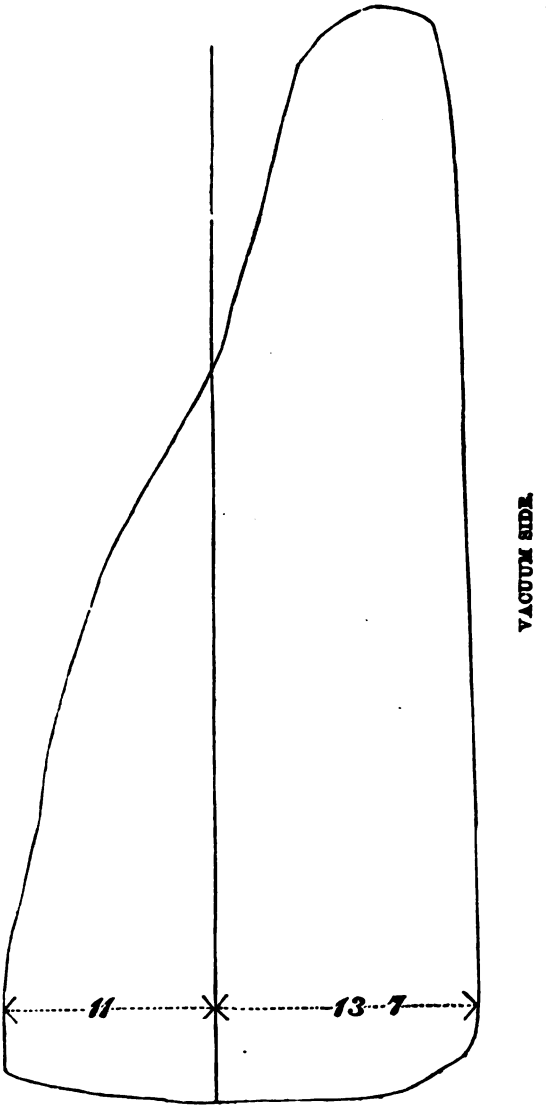


Diagram No. 52.

from the Top of the Low-pressure Cylinder of a Compound Engine.



per minute, the pistons travelling 288 feet per minute. The total area of the two cylinders is 250 square inches.

The diameter of the low-pressure cylinder is 35¼ inches, length of stroke 6 feet, making 24½ strokes per minute, the piston travelling 294 feet per minute. Area of cylinder 976 inches—being nearly four times the area of the two non-condensing cylinders.

From an examination of the high-pressure diagram it will be perceived that the steam is cut off before the termination of the stroke; and that, with the less number of feet travelled per minute, the high-pressure will be about one-fifth the capacity of the low-pressure cylinder—thus making the proportions about five to one. The pressure of steam in the boiler is 55lbs above atmosphere; the pressure on the high-pressure piston is 45lbs, for nearly the full length of the stroke, with a back pressure throughout the stroke equal to 12lbs per square inch. Thus 12lbs is made available on the low-pressure piston, as will be observed by examining the low-pressure diagram. The pressure of steam brought upon the piston of that Engine is 11lbs at the commencement of the stroke, cut off about half the length of the cylinder, expanding the remainder, and making a vacuum of nearly 14lbs. The indicated power of the High and Low-pressure Engines combined, is 250 horse.

The consumption of coal in 77 hours was 22 tons 17cwt. 2qrs.; being at the rate of 2lbs 10ozs. per indicated horse power per hour. The steam is generated in an ordinary double fire-box boiler; and, this considered, the whole presents an example of a compound Engine rarely met with. The cylinders for the high-pressure are much less in diameter than

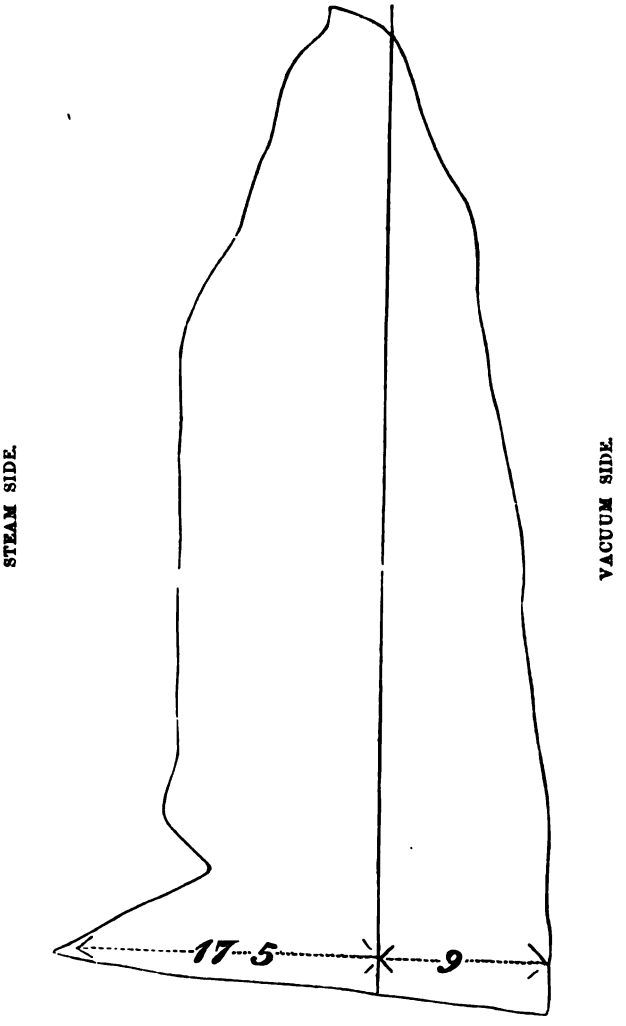
those for most Compound Engines, compared to the size of the low-pressure cylinders. The valves of the low-pressure are set as if the steam was admitted direct from the boiler. They have been so set in accordance with the instructions given in the second edition of this work, the Engineer having the firmness to act upon his own convictions in opposition to the recommendations of the Inspector, who was opposed to the alteration. The great saving of fuel, and the steady working of the Engines, have proved that officialism may be wrong as well as mere guess-work; for inspection without experience, and assertions without reason, are poor materials with which to make improvements. Something more than mere literary display in report-making is required to impart instruction in the practical working of the Steam Engine.

Diagram No. 53 is taken by the same *Indicator* as diagram 52, and is from an Engine at another mill belonging to Messrs. George Andrews and Sons, Compstall, near Stockport. This example ought to convince the most prejudiced, that *the Steam Engine works as it is set to work*, and gives figures and diagrams according to the management. In these two instances we have two Engineers, in responsible situations, at two separate mills under one firm. One Engine is working by and to the *Indicator*, and the other by "rule of thumb;" and although it is visible to the merest tyro in Engineering that the Engine in the latter case does not run properly, and must be consuming at least three times the quantity of fuel consumed by Engine No. 52, besides the constant risk of breaking the Engine up, as before explained, by having the steam too early upon the piston, the

Engineer in command persisted in declaring that "he was all right," and refused to have any alteration made. The diagram makes it plainly apparent that

DIAGRAM No. 53.

Taken from the Top of the Cylinder of a Condensing Engine.

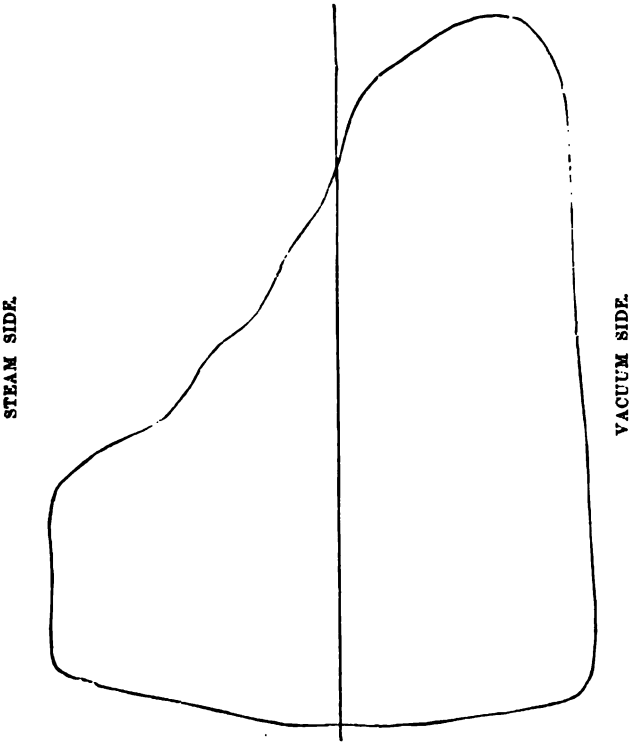


the valves are late in every point, both on the steam side, and on the opening and closing of the exhaust. There is also a poor vacuum; and much more water used to condense with than ought to be necessary. This mode of valve setting causes the Engine to be a most unmerciful gormandizer of steam. In fact, the case is like a mirror—strongly reflecting the wasteful consequences of mismanagement.

Diagrams Nos. 54 and 55 are from No. 2 Engine, belonging to Messrs. HYDE, SONS, AND SOWERBY, of

DIAGRAM No. 54.—FULL SIZE.

Taken from the Top of the Cylinder.

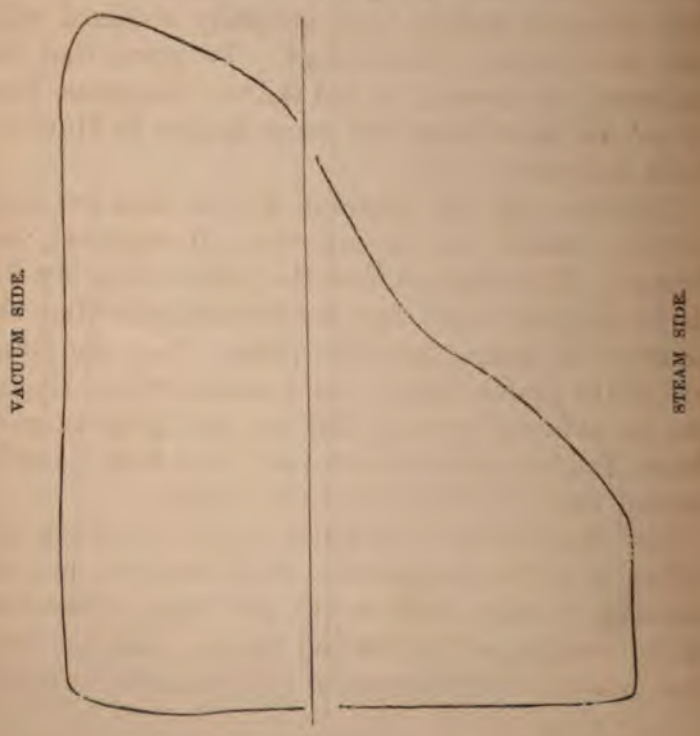


Duckinfield. They were taken by an Inspector employed by the "*Manchester Association for the Prevention of Steam Boiler Explosions, and for effecting Economy in the raising and use of Steam.*" They are given here for the further explanation of the discrepancies which often arise from the use of that description of *Indicator* known as the McNaught.

From diagram No. 54, taken from the top of the cylinder, it appears as if the valves were too late; while from diagram No. 55, taken from the bottom of the cylinder, the valves would appear to be right.

Diagram No. 55.—Full Size.

Taken from the Bottom of the Cylinder.



This is stated to be so in the report sent with the diagrams, which is also here given :—

REPORT.

"The steam is rather late on both sides of the pistons of Nos. 1 and 2 Engines ; also on the top side of No. 2, which a little adjustment of the valves will rectify.

"SIGNED—H. W. HARMAN, *Chief Inspector.*"

When this report and diagrams were shewn to the Engineer, he affirmed that, as it regarded No. 2 Engine, the contrary to what was stated in the report was the fact. From his previous acquaintance with the description of *Indicator* used by the Inspector of the Manchester Association, he was not surprised at receiving such a report, he being well aware that incorrect results were generally obtained with that description of instrument. To prove that his judgment was correct, he had the two diagrams, Nos. 56 and 57, taken from the same Engine by HOPKINSON'S *Indicator.*

Here the top side diagram, No. 56, does not shew that the valves are too late—but, if anything, too forward. The diagram from the bottom side, No. 57, shews that the valves were too forward, admitting the pressure of steam upon the piston when the crank was at the plumb centre—the greatest evil an Engine can be exposed to—one that has cost proprietors of Steam Engines more expense and time from "break-downs" than all other causes put together.

The Manchester Association has yet to learn the difference in the construction of *Indicators*, and the necessity of using such as will give true delineations of the working of Engines and valves. Had they used that description of instrument which records correctly,

Diagram No. 56.

Taken from the Top of the Cylinder by Hopkinson's Indicator.

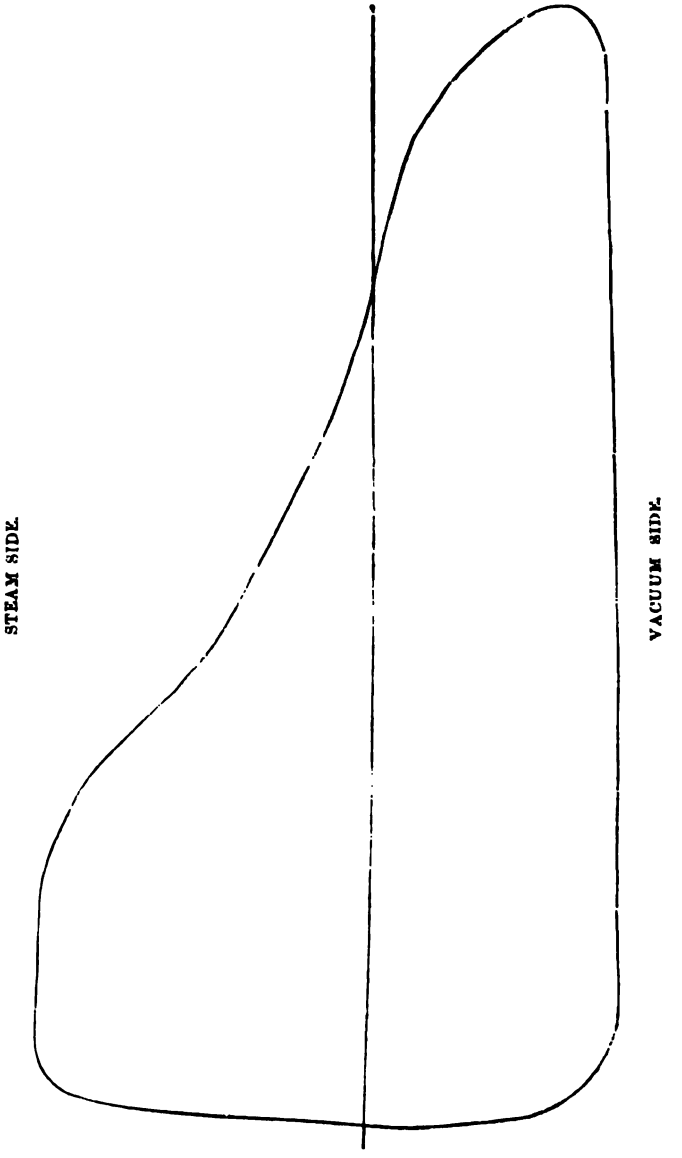
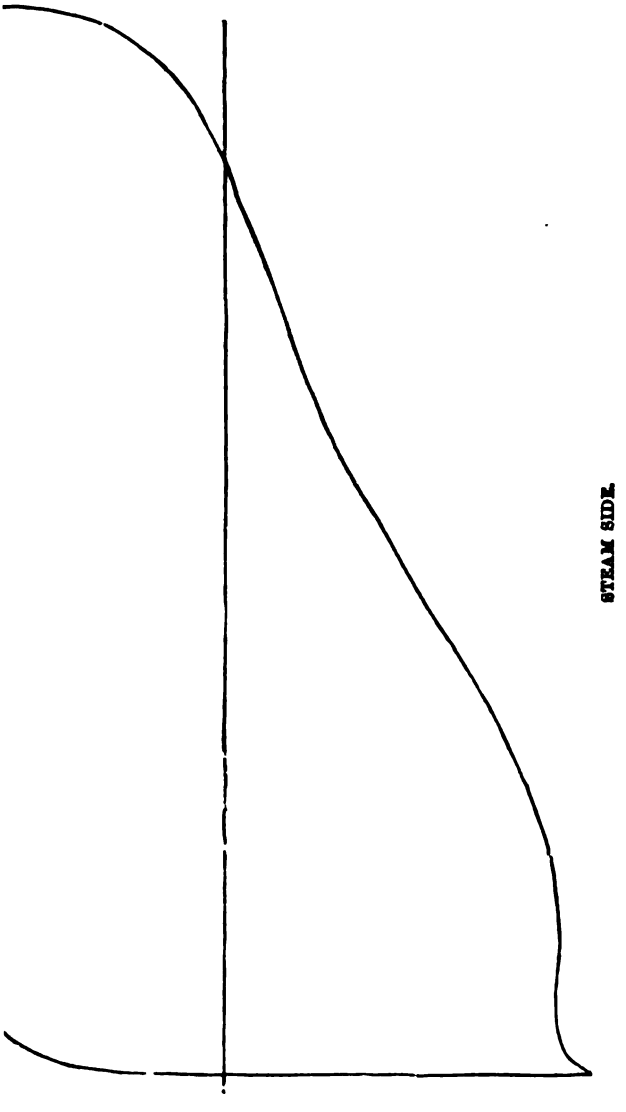


Diagram No. 57.

-om the Bottom of the Cylinder by Hopkinson's Indicator.



such a report as that given above would not have been sent from their chief Inspector. In this instance, the proprietors determined to test the value of the report, and the valves were altered according to its suggestions. The injurious effects of these alterations, as shewn by the working of the Engine, were so apparent that the valves had at once to be set back; and the diagram, which was stated to be correct, was so far altered as to have a rounding at the steam corner, instead of a projection. The Engines are now doing their work well, with the valves set in a *reverse* manner to that recommended in the report.

We have often been called in to deal with cases under similar circumstances. One instance was at Messrs. ADSHEAD BROTHERS, at Staleybridge. Here we found the Engines labouring under extraordinary difficulties—60lbs pressure upon the piston, and a lifting at the centres sufficient to break the Engines down. After indicating, and comparing diagrams with those sent in by the Manchester Association, we found that those taken by the larger and more sensitive instrument were just the reverse of the diagrams of the Association, as it regarded the working of the Engines and the setting of the valves. The cause of the tremendous strain on the Engine was at once made apparent by the large *Indicator*; the valves were re-set, and the Engines are now in proper working order.

In very many instances we have demonstrated the superiority of the larger and more sensitive instrument, as a real *Indicator*, to that of the construction used by the Manchester Association. This has been done by altering the Engines, shewing the Engineers the various stages of the process—taking diagrams

at each slight alteration,—until the Engines were brought, so far as regards their working, into a state of comparative perfection; shewing also, at the same time, that the small *Indicator* would not indicate the slightest difference during the whole of the changes made. We fearlessly assert, that if either the Manchester, or any other Association, continue to work to the indications given by such a class of instrument as they have hitherto employed, they are liable to serious mistakes, particularly where high-pressure steam is used. And then, the system adopted may be objected to on principle. "Office-Engineering" has not brought the Steam Engine to its present state of efficiency; nor has the cotton manufacture grown to its present national importance under red tapism, or official routine. It has acquired its status by fair, free, and unshackled competition, independently of all "authority;" and if the continued progress of the Steam Engine is desirable and worthy of being promoted, that progress can only be secured by Engineers remaining free from divided responsibility —the industrious Engineer left at liberty to apply correct principles to sound practice without the fear or favour of official prejudice.

On the occasion of a recent vacancy for the Chief-Inspectorship of the Manchester Association, Mr. Edward Ingham, of Oldham, a practical Engineer, was one of three candidates selected by the Committee as most eligible for the office, and, we believe, was placed second in the vote. The following letter received from him, treating upon this branch of our subject, we here give, as corroborative of the remarks made:—

"*Croft Bank Mills, Oldham, Oct. 20th,* 1857.

"Mr. HOPKINSON :

"SIR,—Last night, in our Lecture-room, we had a most interesting discussion on the comparative merits and demerits of 'MCNAUGHT *versus* HOPKINSON'S *Indicator*.' I endeavoured to shew that most of the objections raised against HOPKINSON'S *Indicator* were based upon prejudice and false notions. I told them how I myself had been deceived with respect to the weight and area of the piston ; how you had kindly and lucidly explained to me the fallacy of those notions ; and how we were all of us apt to form erroneous notions when led by the judgment of others, without examining for ourselves. I was surprised to find that many in our Association had long entertained correct notions with respect to the sensitiveness of your *Indicator*, but had not had the moral courage to enunciate their views in opposition to currently received notions, until some one, upon whose authority they placed some little weight, had the courage to express similar views to their own. The moment some one whom they durst venture to chime in with, advanced similar ideas to those they had entertained for a long time, they began to give vent to their pent-up feelings, which before they durst not even moot, because different to the views entertained by the majority. I assure you we had a large number present who for a considerable length of time have looked upon your *Indicator* as giving a truer index of the internal workings of the Steam Engine than any other. I hope you will send me your work as early as convenient ; I shall then, perhaps, be able to discover some other important features, upon which I and the rest of my fellow Engineers may have entertained somewhat mistaken notions.

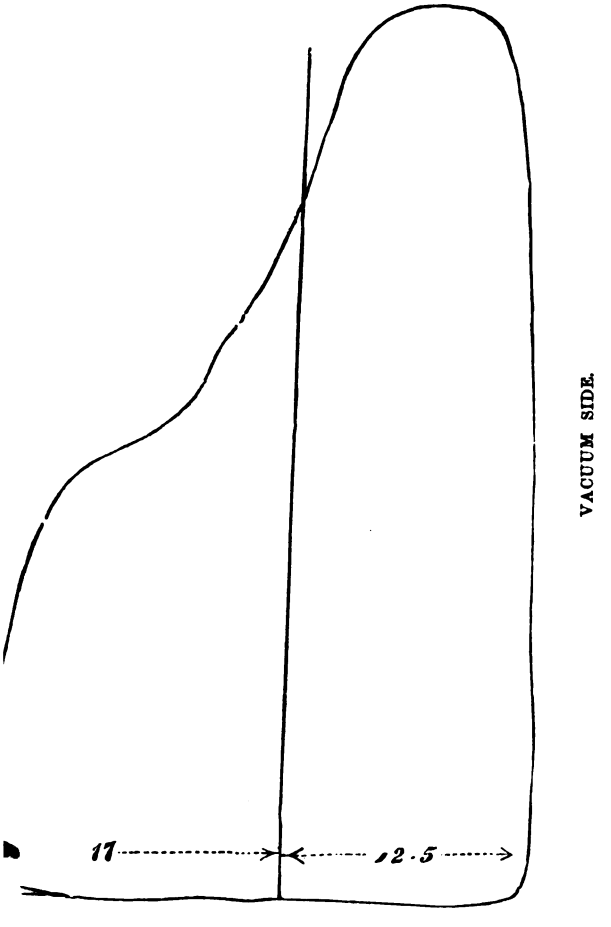
"I am,
"Yours most respectfully,
"EDWARD INGHAM."

Diagram No. 58 was taken from an Engine belonging to Mr. WORTHINGTON, of Hollingwood, near Oldham. The steam was admitted too quickly to the piston, causing the *Indicator* to rebound, making a "zig-zag" line at the commencement of the stroke. A pressure of 23lbs per square inch was brought upon the piston when the crank was at the plumb centre. Many parties in the Oldham district were of opinion

" zig-zag " lines shewn in the diagram arose
fault in the *Indicator*; and they could not
ise convinced until the same instrument,
alves were re-set, produced No. 59 diagram,

DIAGRAM No. 58.

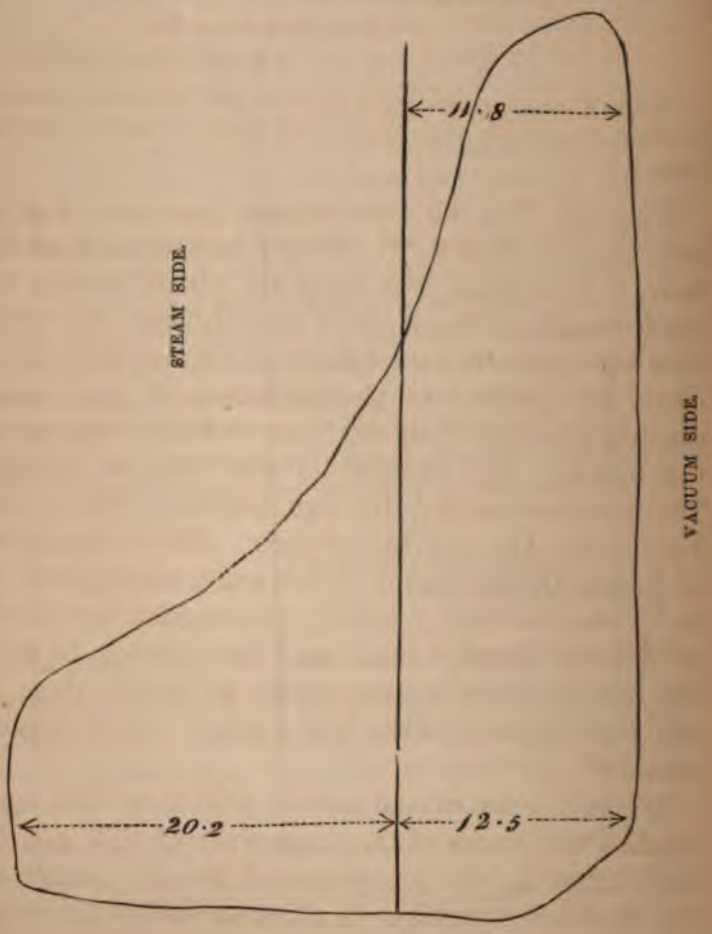
om the Top of the Cylinder of a Condensing Engine.



where the lines are even, and wholly unobjectionable. The "zig-zag" had disappeared; and instead of the projecting corner, as in the former diagram, the corner was a little rounded. The steam was admitted on to the piston both later and more easily; it was also cut

DIAGRAM No. 59.

Taken from the Top of the Cylinder of Engine No. 58.



off earlier, and the exhaust made to close earlier. Accompanying the diagrams taken before and after the alteration, was the following letter from the Engineer :—

"*Hollingwood, August 9th*, 1856.

"Mr. HOPKINSON :

"SIR,—The enclosed diagrams are from the same Engine. No. 58 was taken in March, when the steam was cut off at one-half the stroke. It is now cut off at one-third of the stroke, and the enclosed diagram (No. 59) is our present working.

"Yours most respectfully,

"RICHARD NEEDHAM.

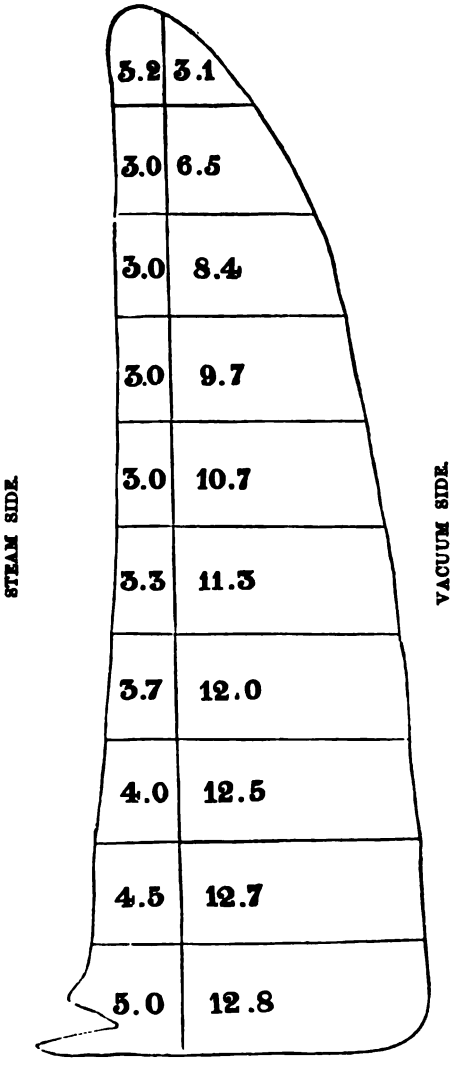
"P.S.—When the exhaust valve begins to open, the distance between the plumb line and the centre of the crank-pin is 24 inches. Six feet stroke."

Diagram No. 60 was taken from an Engine belonging to Messrs. C. MEIGH AND SON, Staffordshire. The steam was upon the piston during the whole length of the stroke ; and although the valve does not appear to have lead on the steam side, yet it opens too quickly at the beginning of the stroke, causing the slight "zig-zag" corner which appears in the figure. The exhaust is also late in opening. The pressure carried by two boilers to drive this Engine was 7lbs per square inch. The consumption of fuel, with the Engine in this state, varied from 50 to 53 tons per week; and it was a regular occurrence to stop the Engine from one to two hours, to clean the fires and get up the steam, to enable them to run the Engine in what was termed "a comfortable manner."

When a copy of the second edition of this work reached the hands of the proprietors of this Engine, they called in the assistance of Mr. E. GLEDHILL, the Engineer referred to in a former part of the work.

Diagram No. 60.

Taken from the Top of the Cylinder of a Condensing Engine.



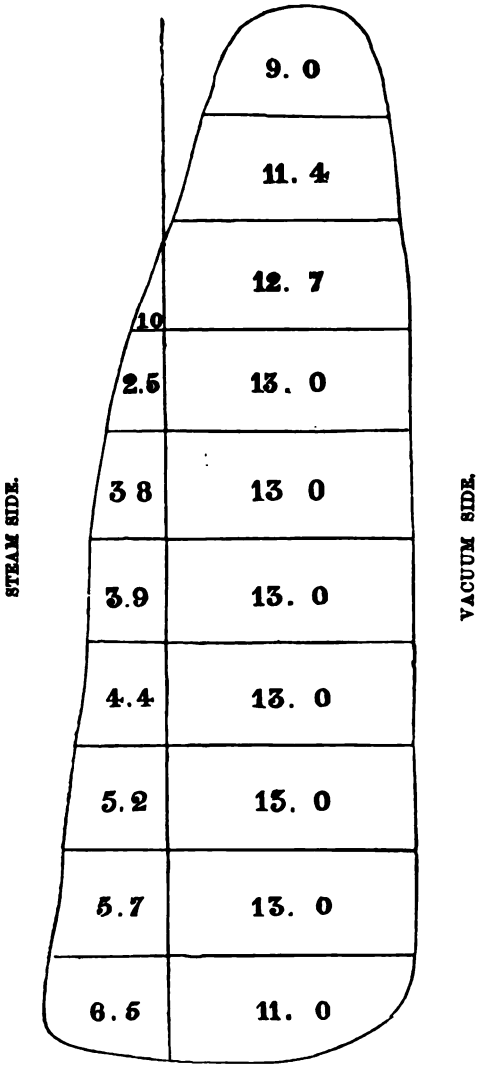
Mr. GLEDHILL made the best alterations he could under the circumstances. He discontinued the use of one of the boilers, and increased the pressure to 15lbs per square inch. He would have increased it still more had he considered the boiler safe beyond that pressure. The valves he re-set, as shewn by diagram No. 61; the steam being cut off about half the stroke, and run down below atmosphere at the termination. The "zig-zag" line is not shewn on diagram No. 61—the valves being set so as to admit the steam upon the piston as easily as possible. To the exhaust he gave more lead, and also caused it to close a little earlier, thus obtaining a much superior vacuum. In consequence of these alterations, the consumption of fuel was reduced from 53 to 23 tons per week; and with this greatly diminished consumption of fuel, there was also obtained an additional power of eight horses.

This is another example which pre-eminently manifests the value of the Steam Engine *Indicator*. Had Messrs. MEIGH AND SON been in possession of that little instrument at an earlier period, and understood it as they now do, they would not, for so long as they were, have been put to such great inconvenience and expense.

Some of those who witnessed the working of the *Indicator*, and its changes of diagrams during the alterations, looked upon the instrument and its indications as something more than wonderful; others considered it must require a laborious study to be able to understand the indications of the instrument. Both parties, however, are much mistaken. The operation of the instrument is natural enough, and a knowledge of its working and use is soon and easily acquired.

Diagram No. 61.

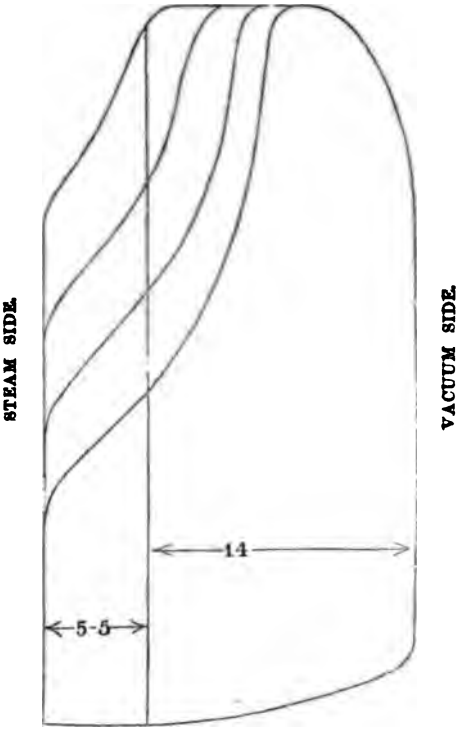
Taken from the Top of the Cylinder of Engine No. 60.



agram No. 62 was taken from the Engine of the tish Queen" steam ship, on Thursday, April 1840. Vacuum, 30½ inches of mercury; steam iler, 6½lbs; expansion tried on ⅜, ½, ⅝, as repre-d by the diagram.

DIAGRAM No. 62.

Taken from the Top of the Cylinder of the Engine of the "British Queen."



e vacuum was the same with or without expan-
As shewn by the diagram, the steam-wa
have been large. The condenser was on
's patent principle of condensing by cold sur

without the water coming in contact with the steam; an arrangement of small tubes immersed in cold water, with the steam passing through them, similar to a locomotive boiler—the water on the outside of the tubes, and the steam in the inside. The pipes are connected at the bottom of the condenser with the air-pump, the air-pump being of the usual size, having only the condensed steam to "lift." An increased vacuum was thus obtained. With this construction, the condensed water is always used in the boiler over and over again, to the prevention of deposit or scale in the boiler.

It is near thirty years since Mr. HALL introduced the principle of condensing steam by surface condensers—particularly for Marine Engines. At first he met with great opposition to his plan. Time, however, has demonstrated the utility of the arrangement; and the original Inventor of the plan has been forgot by the numerous patentees for surface condensers which have lately swelled the patent list, all of the plans so patented being, in principle, the same as Mr. HALL'S—varying only in detail.

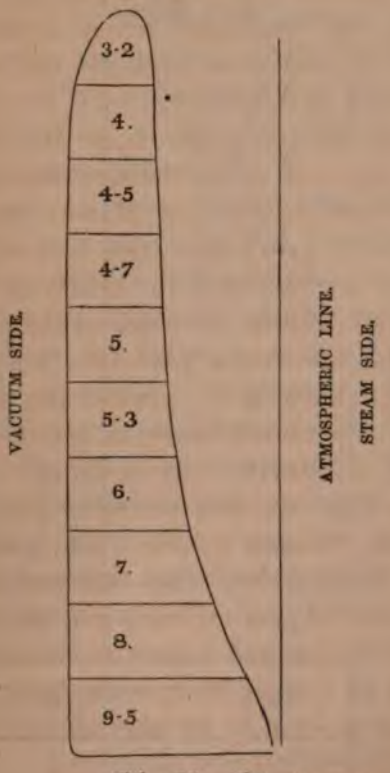
Diagrams Nos. 63 and 64 were taken from the Engines of the "Great Britain" steam ship, from the bottom of the cylinder. No. 63 was taken at the commencement of her sailing; and No. 64 after her Engines had undergone extensive alterations, under the direction of Messrs. MAUDSLEY, SONS, AND FIELD, London, just previously to her misfortune at Dundrum Bay.

Diagram No. 63 shews the utmost mean pressure at which the Engines of the "Great Britain" could be worked, as they were originally constructed, and left by the makers. Diagram No. 64 shews the mean

essure attained after the Engines were altered. om these last it will be seen that the attainable an pressure had been increased from $5\frac{3}{4}$lbs per uare inch to $11\frac{3}{4}$lbs. The consequent increase in the

DIAGRAM No. 63.

Taken from the Bottom of the Cylinder of the Engine of the "Great Britain."



$57\frac{1}{2} \div 10 = 5\frac{3}{4}$lbs Average.

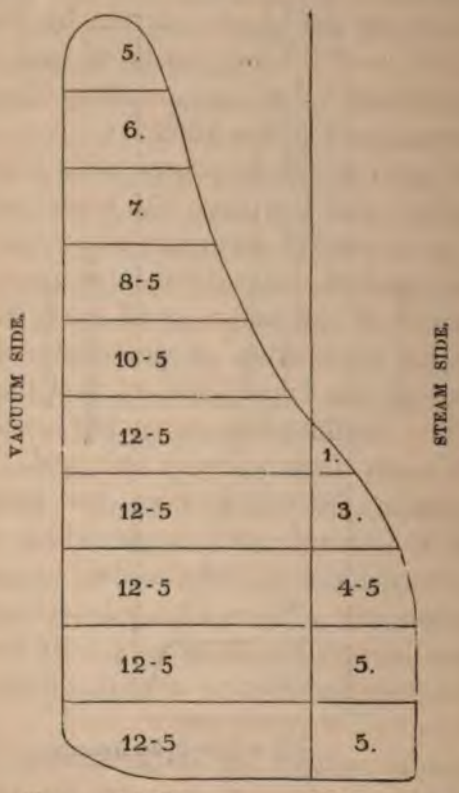
mber of strokes per minute, was from 1
. From this data, and keeping in mind t
linders were 88 inches in dian and th

of the stroke six feet, we arrive at the following calculation as to the number of horse power exerted before and after the change in the Engines :—

Horse Power before the Change :—6082, the area of the cylinder ; multiply by 12, twice the length of the

DIAGRAM No. 64.

Taken from the Bottom of the Cylinder of the Engine of the "Great Britain."



Vacuum 9·95lbs.

1·85lbs Steam.
9·95 Vacuum.

11·80 Average Pressure.

stroke; multiply by $13\frac{1}{2}$, the number of strokes per minute; multiply by $5\frac{3}{4}$lbs, pressure per square inch of piston: divide by 33,000, and it gives 171·6 as the horse power of each cylinder; which, multiplied by 4 (the number of cylinders), make the total horse power 686·4.

Horse Power after the Change :—6082, area of the cylinder; multiply by 12, twice the length of the stroke; multiply by 16, the number of strokes per minute; multiply by $11\frac{3}{4}$lbs, the average pressure per square inch upon the piston: divide by 33,000, and it gives 415·8 as the horse power of each cylinder: which, multiplied by 4 (the number of cylinders), make the total horse power 1663·2.

The real gain in horse power was, therefore, as 1663 is to 686: not less than 976 horse power additional! An enormous difference this: and the more remarkable, because not attained by an increase in the dimensions of the boiler, or of the cylinders, but simply by an application of practical skill in the development of the capabilities of the Engines and boilers. The fire-flues and steam-ways, which before were ridiculously narrow, were enlarged. The air-pumps, which previously bore no proportionate relation to the steam cylinders to which they were applied, were made equal to the duty required; and the expansion valves were adjusted according to the pressure, as diagram No. 64 evinces. By these means the utmost possible amount of work obtainable from each cylinder full of steam was realized.

This example shews the importance of the *Indicator*, and the paramount necessity for parties connected with the making or erecting of Steam Engines, to study its indications in detail. What prevented

the first constructor of these Engines from ascertaining the fact that he had crippled the power of his Engines most enormously? The want of a thorough knowledge of that simple and efficient instrument, the *Indicator!* Had he been practically acquainted with the use of that instrument, he could not have perpetrated such a glaring blunder as he committed in turning out such inefficient machines: for he would have met with many instances which would have shewn him the necessity of having abundance of steam room through the pipes and valves. There is a wide difference between what may be termed "Office-Engineering" and Engineering founded on practical experience and observation. The latter, though sometimes dogmatic, and unwilling to receive new theories, or to depart out of a favourite track, is often of essential service to the former; for, from the most obstinate something useful may be learned.

Diagram No. 65 was taken from an Engine belonging to Messrs. HIRST BROTHERS, Corn Millers, Leeds Road, Huddersfield. From the diagram it will be perceived that the steam is on for the full length of the stroke, the valve being a three-port, having little or no "lap," and traversing the full length of the valve-box: consequently there is no room for "lap" to be added to the valve in the ordinary way. The steam, therefore, as is shewn by the diagram, is not expanded, but has to be condensed at atmospheric pressure.

Diagram No. 66 was taken from the same Engine, after some alterations had been effected. The steam is now cut off at one-third of the stroke. This had been accomplished, not by adding "lap" to the valve, there being no room in the valve-box; but by making

Diagram No. 65.

'rom the Top of the Cylinder of a Low-pressure Condensing Engine.

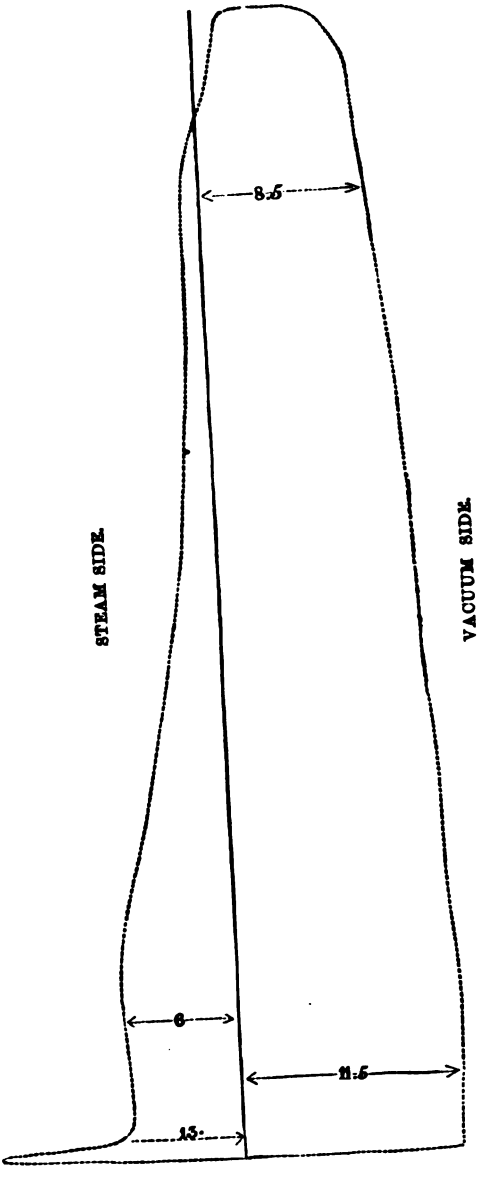
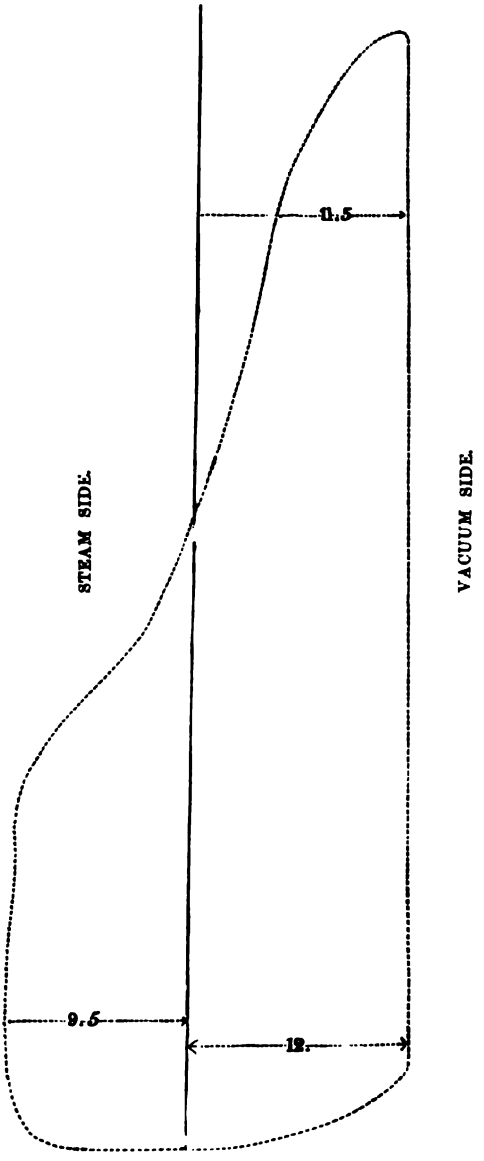


Diagram No. 66.

Taken from the Top of the same Cylinder as No. 65.



the thoroughfares less, which had the same effect as adding "lap" to the valve. This process is technically termed "bitting the thoroughfares" (see explanation, page 60). On an examination of the two diagrams, it will be observed that in the one case there was steam to condense at atmospheric pressure, while in the other the steam to be condensed was 5lbs below atmosphere—taking less water to condense with, and less power to work the air pump. When the air pump is heavily loaded, the Engine will not run steadily, because of the uneven strain upon the parts. The pump only has to lift at one portion of the stroke; and the weight then added often causes an uneven motion. The consumption of fuel, after the alteration, was found to be 25 per cent. less than before, with the Engine working much better, and with less strain upon the parts. Under the altered circumstances the steam was not introduced to the piston as early as before, and the exhaust opened and closed sooner. In a letter from Messrs. Hirst Bros., they state:—"We had expended considerable sums, at the advice of other Engineers, but all to no purpose. The Engine is now considerably improved in its working, and the alteration has effected a saving of coal to a large amount." This Engine could be further improved, were it altered so as to work at a greater speed. Engines for corn mills should traverse at a quicker rate than most other Engines—because where the speed of the work driven,—mill-stones for example,—is great, the speed of the Engine should be greater: if not, there will be what is termed a "back lash," and great wear and tear is the result under circumstances of that nature.

EXAMPLES FROM THE "GREAT EASTERN" STEAM SHIP.

The performances of the Engines of the "Great Eastern" have naturally been regarded with great interest in the Engineering world; for upon their good work depended, in a great degree, the rapid passages she was expected to make.

At the time this chapter was written, she had only made one trip across the Atlantic, the voyage from Southampton to New York, occupying 11 days and two hours, being an average run of 13 knots per hour. Although this was not so rapid as was anticipated, yet according to the reports, everything went off highly satisfactory. The Engines, it was stated, worked well.

With such a gigantic undertaking, a vessel which may be truly termed a floating city, it is essential that safety and economy in every department should be studied; especially the former, that we may not again have another catastrophe similar to that which occurred on her first trial trip in the Channel,—viz: the bursting of one of the water-heaters in connection with her boilers.

So far as regards the construction of the boilers, the public were informed, during the progress of the ship when on the stocks, that they were on the best principle, calculated to work with greater economy and safety than those of any vessel hitherto afloat. To the really practical Engineer there was no matter for surprise in the disastrous occurrence which took place, as it was what might have been expected with such a construction. Nor does it appear in any manner singular that the construction should have

been approved of and adopted, when we find the opinions of men taken and acted on, who, according to the evidence given before the Coroner's Jury, had no idea at all approaching to the accuracy of the pressure which caused the explosion: that evidence affording the fair inference that their knowledge of construction was very limited, or they could not have made such extraordinary statements.

The scientific gentlemen who were examined varied in opinion regarding the pressure required to collapse the large tubes which gave way; some gravely stating that there must have been at least a pressure of 600lbs per square inch, whilst others were more moderate. Evidence of such a character only denotes a want of experience; for those who have paid attention to boiler explosions and their causes, know that those who gave such evidence as we have indicated, must either have been playing upon the credulity of the jury, or were themselves awfully deficient in a knowledge of boiler Engineering.

It is well known by those who have been in the habit of testing steam boilers, that there is a vast difference betwixt the power of a tube of any given diameter to resist pressure exerted external to that diameter, and the power of one to resist pressure exerted internal to the diameter; and that a tube decreases in its resisting power, both externally and internally, as the diameter increases. It follows, therefore, that the internal tube, or flue of a boiler, is much weaker than the outer shell.

If we take the bursting pressure of the outer shell, or flue case, of the "Great Eastern" to have been 250lbs per square inch, with the pressure exerted internal to the diameter, we assert that the same tube

with the pressure exerted external to the diameter, would collapse with less than one-sixth of the 250lbs pressure. At the time of the occurrence, contending against the evidence given, the writer took up the matter, and endeavoured to demonstrate that, under all the circumstances, the pressure in the case at the time of explosion could not possibly have exceeded 29lbs. The following letter on the subject appeared in the *Mechanics' Magazine* of Oct. 14th, 1859 :—

"TO THE EDITORS OF THE 'MECHANICS' MAGAZINE.'

"GENTLEMEN,—I am not about to discuss the question who was in charge of the Engines and boilers of the 'Great Eastern,' or who was responsible for the explosion, having only a right to interfere on public grounds, and to further the research as to the real cause, with a view to a prevention of such calamities.

"I have for a considerable time called the attention of the public to the frequency of boiler explosions, and their probable increase, unless more attention be paid to construction and management; more particularly to that form of boiler known as the Cornish boiler, in which the pressure is exerted upon the outer portion of a cylinder. In April, 1855, I wrote a letter to the *Manchester Guardian* on this particular form of boiler, which began thus :—

"'Another boiler explosion, attended with a lamentable loss of life, is recorded in your journal of this day. Pending the judicial inquiry which must take place into the facts of that case, I do not intend to comment on the details as set forth in your report, beyond calling attention to the fact, that the part of the boiler which has given way and occasioned this lamentable catastrophe, is one of its *internal flues*, which had to sustain a great pressure exerted externally upon its cylinder-like form, and which at length failed under the strain to which it was subjected. The many instances of boiler explosions, arising from the collapse of internal flues of this character, ought surely to induce a more serious inquiry than the subject has yet received, with the view of ascertaining whether boilers of this, the favourite form of construction, are safe when worked at the high pressures now deemed desirable, or, indeed, at any considerable pressure; or whether a collapse of the flues is not a certain result of the force so applied, and in the best of boilers,

and under the most favourable conditions, *only a question of time.* For myself, from inquiry and reasoning upon the subject, I have long since arrived at the conclusion that this form of boiler, whether of the kind known as the Butterley or the Cornish, is not safe.'

"At Leeds, last year, I read a paper on the subject before Section G of the British Association, which you were kind enough to publish in the *Mechanics' Magazine*, of Oct. 23rd, 1858.

"The portion of the boiler that exploded in the 'Great Eastern,' was that portion of the flue or chimney which extended from the top of the boiler to the upper deck. That flue or chimney was surrounded by another cylinder, 12 inches larger than the internal flue, being seven feet diameter, leaving a water space of six inches betwixt the flue and the case, and extending in height, or length, 40 feet from the boiler. This case, when charged with water, would have a pressure of 18lbs per square inch at the bottom, internal to the outer shell or case, and external to the flue or chimney.

"The outer shell or case was provided with an open stand-pipe proceeding from the bottom, and extending to a height of 25 feet above the top of the case, in the form of an inverted syphon, the descending pipe being attached to the top of the outer shell. At the extreme height, in the curve of the syphon, a half-inch hole was bored, at all times open to the atmosphere. In the descending leg of the pipe, just at the top of the water-space, was inserted a stop-tap, to cut off communication, and prevent the steam from entering the descending pipe, or short leg of the syphon.

"Having described this portion of the boiler to the best of my information, I will now endeavour to explain the cause of the collapse of the flue. It was stated in evidence that the supply of water to the outer case was stopped, and that the tap in the short leg of the stand-pipe was closed. Such being the case, I shall endeavour to shew that this construction of water-heater is one highly dangerous, not on account of the heat to which it may be exposed, but from the fact of a six feet tube being subjected to pressure exerted external to its diameter.

"Many parties imagine that the heat given from the furnaces of the 'Great Eastern,' when passing up the chimney, would be very high, and consequently that there would be a rapid generation of steam in the case: and that by the tap being closed, there would be an immense pressure brought to bear upon the chimney or flue, and the water-heater. In the first place, I assert the heat traversing through the flue would never exceed 450 degrees Fahrenheit, and I very much question whether

it would reach 350 degrees in so large a space as a six feet diameter flue. In making this statement, I do not merely imagine such would be the heat given out. My conclusions are from actual test of a similar boiler. But I will grant that the temperature was 450 degrees in the flue. At that temperature it would at the very least take twelve hours to get the water in the case to boiling point; and to generate a pressure of steam of 20lbs above atmosphere would require 260 degrees of heat in the case, which I aver was never the fact in the exploded funnel.

"It remains to shew the real pressure of steam that would have to be generated in the heater sufficient to force the water out at the top of the pipe. It must be borne in mind that the 1½-inch stand-pipe went to the bottom of the case, and was open from end to end, extending to a height of 25 feet above the top of the case; and that there was a ½-inch hole at the top to let out the steam from the heater, or, as at the time of the explosion, to let out the water when the tap on the top of the water-heater was closed. There requires no comment as to the probable pressure of steam in the case. A pressure of 11lbs per square inch was sufficient to force the water out at the top of the pipe; and thus I come to the undeniable conclusion, that the steam in the case did not exceed 11lbs per square inch at any time. Had the tap been open, the half-inch hole would have been sufficient to have discharged as much steam as twenty such water-heaters would have generated.

"Having shewn that the steam pressure could not be more than 11lbs, I come to another point regarding the pressure brought to bear externally upon the six-feet diameter. The water-heater, as described, was 40 feet high, and unless it was completely filled with water, none could be supplied to the boiler. A column of water of that height would exert a pressure of nearly 18lbs per square inch at the bottom end of the case; and that, added to the pressure in the stand-pipe, gives a total of 29lbs per square inch, being the extreme pressure that could be brought upon the water-heater. Now the question arises, at what pressure did that internal flue collapse? It is perfectly clear that it collapsed at less than 29lbs per square inch. Therefore, the flue must have been weaker than the stand-pipe denoted, being constructed, as they perhaps presumed, to work with safety at 29lbs per square inch.

"I have repeatedly called the attention of boiler-owners to the case of the 'Victoria,' whose boilers twice collapsed, and killed eleven persons. A searching inquiry took place as to the cause.

"The 'Victoria' exploded in 1838. The flues were six feet diameter, made of ¼-inch Low Moor plates; and they collapsed at a pressure of

13lbs per square inch, viz., 10lbs of steam and 3lbs of a column of water. The flues were repaired, and they again collapsed at the same pressure. The collapse on board the 'Great Eastern' was precisely similar, except that the flue was six feet diameter, with ½-inch plates; yet we find that although double the thickness of the 'Victoria,' there is no proof that it took more or less than double the pressure, 26lbs to collapse the flue in the 'Great Eastern,' as there was no means of ascertaining what was the height of the column of water in the stand-pipe; but certain it is that it collapsed under 29lbs pressure. I am fully persuaded that the cause of the collapse of the flue on the 'Great Eastern' was from defective construction; that the pressure exerted external to the six feet flue was too much for that diameter to resist.

"As a water-heater, I denounce this construction as being highly dangerous, arranged, as it was—having a stand-pipe attached, so as to increase the pressure. There is no doubt that the impression was that the flue was sufficiently strong to carry that pressure, otherwise the stand-pipe would not have been erected. Therefore the blame is not justly cast on the person who closed the tap—although I acknowledge the explosion would not have occurred at that particular time, had the tap been open. It remains for those who applied the stand pipe to say whether they considered the flue sufficiently strong to resist the pressure the stand pipe would bring upon it in case of the tap being closed. I cannot but think that such was the opinion, or why carry the stand pipe to such an elevation?

"Your obedient Servant,

"J. HOPKINSON.

"Britannia Works, Huddersfield, Oct. 4th, 1859."

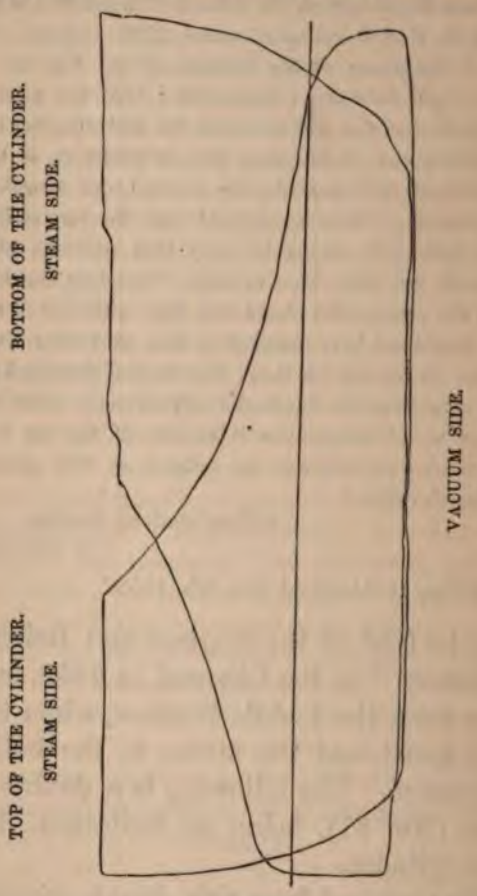
During the trial of the Engines and Boilers of the "Great Eastern" in the Channel, in 1859, indications were taken from the Paddle Engines, when the vessel was at full speed, and the steam in the boiler at its highest pressure. The following is a double diagram then taken (No. 67), being an indication from each end of the cylinder.

It will be observed from this double diagram, that to a great extent the valves were unevenly set. The diagram from the top of the cylinder shews that the pressure upon the piston was 20lbs above atmosphere,

cut off at one-third the length of the stroke, and expanded down to atmospheric pressure at the termination. The diagram from the bottom of the

DOUBLE DIAGRAM.—No. 67.

Taken from the Paddle Engines of the "Great Eastern."



cylinder shews that the steam was upon the piston equal to 22lbs above atmosphere, cut off at half-stroke, and expanding down to 4lbs above atmosphere at the

ation; in both cases the vacuum was 12lbs. umber of strokes was $11\frac{3}{4}$, and the speed of the 331 feet per minute. The exhaust closed when ston had travelled five-sixths of the length of

DOUBLE DIAGRAM.—No. 68.

aken from the Paddle Engines of the "Great Eastern."

der—checking the progress of the piston wards of tw from the end of the

No. 68 is also a double diagram, taken June 26th, 1860, when the "Great Eastern" had been nine days out on her first voyage to America. The pressure on the boiler was 26lbs per square inch above atmosphere; and 21lbs were brought upon the piston at the bottom portion of the cylinder. The steam was cut off at a little before half-stroke, and expanded down to 4lbs below atmosphere at the termination. On the top portion of the cylinder the steam exerted a pressure of 30lbs at the commencement, and was cut off a little past half-stroke. The average pressure was 23lbs up to a little past half-stroke. It then expanded to 2lbs above atmosphere, making only a 9lbs vacuum. The exhaust begun to close at one end of the cylinder when the piston had to travel two feet of the stroke, and at the other end the exhaust begun to close when the piston had to travel one foot. It will be perceived that as the valves were then set, they were in many respects different to the position Mr. Scott Russell had them when on the trial trip in the Channel, so far as regards the admission of the steam and the cut-off.

There are objections to the setting of the valves in both instances; but on the whole Mr. Scott Russell's diagrams are superior.

The early closing of the exhaust, with Engines travelling only $11\frac{3}{4}$ revolutions per minute, is a defect calculated to reduce the power considerably, from the Engines having to compress such a great quantity of steam as was left in the cylinder, with a 9lbs vacuum. This necessarily acted as a retarding force against the piston's course. The steam thus left in the cylinder had to be compressed to a greater pressure than that which was in the boiler. The diagram shews that

there was a compressed force of 30lbs, which had to be overcome by the force of the other Engine when at its full power, assisted by the motion of the ship. If these Engines had been separate, and not attached to a heavy fly-wheel or some other body in motion, the piston would have stopped before it arrived at the end of the cylinder, because the compressed or "cushioned" steam would have been of a much greater power, or pressure, than the steam on the propelling side of the piston, or that in the boiler. This resulted because the steam left in the cylinder could not escape, on account of the exhaust valve closing too soon. Of course this was a serious drawback to the working of the Engines, involving a loss of fuel, besides exposing the Engines to the danger of breaking down, by having such a force as 30lbs of steam above atmosphere upon the crank and piston at the plumb centre—almost as bad as "priming" in the cylinder. There need be no wonder at the comparatively slow speed these Engines attained.

Without taking into consideration various other defects in the latter arrangement of the valves, there is an almost unpardonable defect which we must notice—the small amount of vacuum obtained. On one side of the piston this only reached 9lbs, and on the other 10lbs, which, contrasted with the diagrams taken on the trial trip, shewed a deficiency averaging 2½lbs per square inch throughout the whole of the working. On one side it was 3lbs, which proved there was something that required attention. That 4lbs of deficiency in the vacuum proved the simple fact, that an extra pressure of 4lbs of steam was required to give out the power that a proper condensation should have given: in other words, there was a loss of 20

per cent. in fuel, or 20 per cent. in power. That loss of vacuum, and the loss of power at each end of the stroke, to a great extent account for the slow speed of the Engines, and the great quantity of fuel consumed.

THE SCREW ENGINES OF THE "GREAT EASTERN."

Diagram No. 69 was taken from the Screw Engines of the "Great Eastern," on June 26th, 1860, during her first trip to New York. The pressure of steam in the boilers was 20lbs; the speed of the piston 285 feet per minute. The pressure of steam above atmosphere brought upon the piston at the bottom end, was 16lbs; at the top end, 18lbs, with a partial cut-off and the ordinary closing of the valve, leaving steam above atmosphere to be condensed at the end of the stroke, and making a vacuum of from 10lbs to 11lbs per square inch. The steam being exhausted when the piston has to travel one-seventh the length of the cylinder, that portion, or nearly one-seventh of the power was lost—the steam being condensed before it had given out its full power. The steam ought to have been better used up.

There are other minor points in connection with these diagrams that might be observed upon, such as the projection on the bottom diagram; but as we suppose the reader will, by this time, have acquired a tolerably accurate knowledge on the subject, and be able, of himself, to point out or comprehend such defects, we do not deem it necessary to dilate upon them.

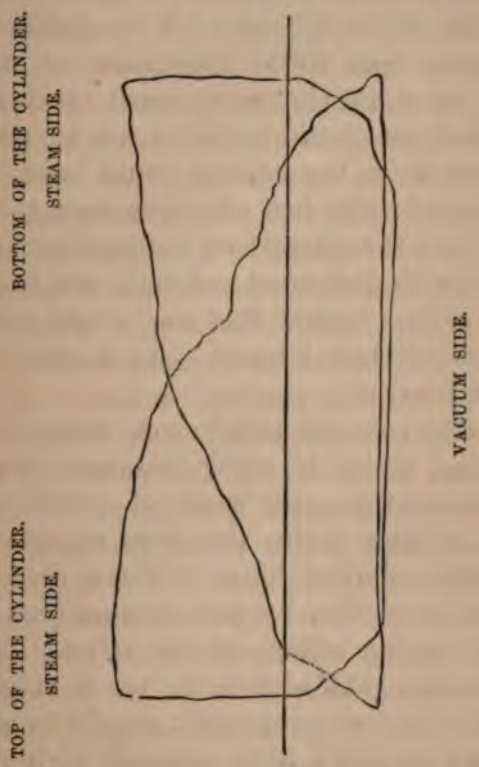
For these diagrams we are indebted to the courtesy of the Editor of the *Mechanics' Magazine*, whose

kindness in enabling us to lay such interesting examples of the performances of the Engines on board the world-renowned ship, we hereby gratefully acknowledge.

In connection with such a stupendous and magnificent undertaking as the "Great Eastern," it is

DOUBLE DIAGRAM.—No. 69.

Taken from the Screw Engine of the "Great Eastern."



highly essential that every one having a knowledge on any detail connected with her efficient working, should impart that knowledge. The importance of

economy and safety in the working of the Engines of such a vessel is undoubted, both in a national and commercial sense. It is therefore from a desire to aid in the development of the full resources of her power, thus enabling us still further to extend the national might and influence of this particular branch of navigation, that the author ventures to remark upon the unsatisfactory manner in which these Engines were left, and their consequent inadequate performances. So far as regards the manner in which Mr. SCOTT RUSSELL left his Paddle Engines, they were not open to the objections that afterwards applied to them, in what was termed "their improved state." Had an *Indicator* been used such as this work treats upon, the defects would have been still more apparent; and had attention been given to the diagrams, and the alterations required been properly carried out with judgment and skill, the Engineering managers of the "Great Eastern" might indeed have been proud of their labours. As it was, they had nothing to boast of.

It has often been our task to comment on inefficient valve setting, which in many instances results from deficient education, or want of practice in the Engineer, arising from the few opportunities of improvement afforded him. There are, however, self-taught men, who, by perseverance and the good fortune of having witnessed the effects of various alterations, now rank high in the art of valve setting. To men of this class every credit should be given. To those, however, who have attained high repute as Engineers, and who have had every possible chance of information and experiment, and who send forth such diagrams as those we are commenting on, which,

from the size and construction of the Engines, ought to be unequalled, what can we do but award them only a second place, because not entitled to take rank amongst those whose higher productions of skill are set forth in the course of this work—examples which would do honour to any Engineering department in the world? What should have prevented the Engines of the great ship from working equally well to those to which we allude, except the want of a practical knowledge of the *Indicator*, and the proper modes of valve setting? This art is not to be acquired in the study. It must be attained by perseverance and personal observation in the Engine-room; by noting the various changes produced by the slightest alteration in the valves. It would be well were more practical experience and less office routine applied to Engineering in general.

As examples in contrast, we refer the reader to diagrams taken from other Engines, and ask him to compare the difference produced by better valve setting. In a subsequent part of this work, illustrating the work of a Direct Action Engine, there will be given a diagram from an Engine belonging to Messrs. J. Crossley and Sons, of Halifax. The circumstances of the two cases were similar, so far as regards the pressure of steam; but what a different vacuum in the one instance, when contrasted with the other! and especially when we state that in the Halifax Engine the injection water was at 100 degrees in temperature, while in the case of the "Great Eastern" there was the water of the broad ocean at the service of her Engineer. This shews the nature of the attention paid to the working of the Engines at Halifax, there being produced in that instance a

vaccuum of 12·5lbs, being 3½lbs superior to that of the "Great Eastern." At page 164 there is a double diagram (No. 50), taken from the Engines belonging to Messrs. HYDE, SONS, AND SOWERBY, which speaks for itself. Had the Engines of the "Great Eastern" made such diagrams, and exhibited such a vacuum, as they certainly ought to have done, the power would have been much increased, less fuel would have been required, and the wear and tear would have been greatly reduced. It must be borne in mind that a constant uneven strain upon the parts of these Engines, with pressure on the crank when at the plumb centre, tended more to destroy them than a greatly increased pressure properly applied. The best schools in which to learn the art of valve setting are the spinning concerns of Lancashire, where the machinery is run at tremendous speeds, and where the utmost regularity is required. In that school the student would soon discover that such valve setting as that of the Engines of the "Great Eastern," would have to be dispensed with.

Marine Engine valve setting has yet to undergo great improvements to get the full amount of power from the steam consumed.

In most of the diagrams we have seen from Marine Engines, there is evidence of "a rule" which their valve setters work by, but which is not of the best. The steam is generally admitted to the piston too early and too quickly, and the valves close too quickly in the exhaust—the latter point requiring to be adjusted with nicety, so as not to destroy the power and regularity of the steam. The examples of valve setting given at pages 144, 149 and 151, (diagrams Nos. 26, 44 and 45,) may be beneficially studied by

the marine Engineer; and we trust the remarks and suggestions here made will be the means of an extended inquiry into a subject worthy of the practical Engineer.

The reader who was not practically acquainted with the *Indicator* when he first took up this work, if he has closely and attentively studied the examples we have given, will by this time have gained some information respecting the mode of operating with, and also the uses and advantages of, this invaluable instrument. The diagrams taken from the Engines of the "Great Britain" (Nos. 63 and 64), and those from the "Great Eastern" (Nos. 67, 68, and 69), offer in themselves so strong a case that it requires no lengthened argument to shew the important advantages to be derived from such an instrument. By what other means are we to ascertain the power of an Engine? or ascertain how the pressure of the steam is exerted upon the piston of the Engine? or the quality of the vacuum? Is there any other certain mode of making these apparent? If not, how can any one describe the working condition of an Engine, if he be ignorant of the working of the *Indicator?* Such a thing is simply impossible.

There is, therefore, every necessity for all connected with the working of Steam Engines to make themselves thoroughly acquainted with the practical use of the *Indicator*; for without that knowledge no man can be said to thoroughly understand the Steam Engine in detail, but must be wholly ignorant as to any certainty of its internal workings. Without this instrument no man can manage the Steam Engine

without a [illegible]
without tools [illegible]
management of a [illegible]

WORKING STEAM EXPANSIVELY IN ONE CYLINDER.

THERE are two modes of applying the power of steam to the working cylinder; namely, one allowing steam to flow from the boiler during the whole length of the stroke; and the other, cutting it off from the boiler when the piston has travelled a determined distance—the great and paramount object of this last arrangement being a saving of fuel.

If steam be applied the full length of the stroke, the average pressure will be as the pressure per square inch upon the piston; but if the steam be cut off at half-stroke—suppose the pressure to be 65lbs per inch when the pressure of the atmosphere is added,—there will be a mean equivalent, or average pressure, throughout the stroke, of 55lbs per square inch; being only 10lbs less than the full pressure, or 16 per cent. of a loss in power, though half the former quantity of steam has only been used. This alone effects a saving of 34 per cent. in fuel, and shews the great benefit to be derived from expansion in one cylinder.

If this principle be true—and its truth is undeniable—it is quite evident that the greatest economy will result from extending expansion to its full limit, and making the cylinders of Steam Engines of sufficient capacity for this purpose; though with the high-pressures with which expansion is most available, they will require to be less than are usually made, to

show the Engines
The table—which ap
of the work—will sh
and, the average pres
when cut off at any po
begins at 10lbs above
in lbs up to 150lbs p
will enable the Enginee
pressure the amount of
power to be obtained, a
desired.

The principle of expand
Rotary Engine is the same
Engine, excepting that the
the atmosphere, cannot exp
ind, because the exhaust i
the atmosphere in all cases
atmosphere, 15lbs, must be a
steam above atmospheric pre
the pressure of the expansi
piston. For example: steam a
the atmosphere upon the piston
the stroke, will be 8¾lbs at th
stroke, as shewn by the following
added to 15lbs, the pressure of th
35lbs. This divided by 4, give
Thus, 8¾lbs is the pressure at the
stroke, or 6¼lbs below atmosphere
following diagram and the explana
principle more fully.

A represents the cylinder of a
divided into eight equal parts. The
steam used is supposed to be 50lbs p
e the pressure of the atmosphere.

cut off at one-eighth the stroke, and the
travelling the other seven portions by the
expanding steam: in calculating what will
ssure at the termination or at any other
the stroke, add the pressure of the atmo-
he pressure of the steam above atmospheric
Thus in this case: 50lbs added to 15, equals
ivided by 8, gives $8\frac{1}{8}$. To make this rule
ctly understood, let the Engine-man add
e pressure of the steam and the pressure of
here, and divide by the number of expan-
he quotient will give him the pressure on
at the end of the stroke. For the average
on throughout the stroke, see the accom-
ble Appendix A;—which average will be
25lbs throughout the whole of the stroke.

A

steam on the piston of an Engine through-
ke at 65lbs pressure, the average is as the
65lbs: by cutting off at one-eighth of the
average is 25lbs. It therefore follows that
use one-eighth the quantity of steam to
as we use for the one stroke with steam

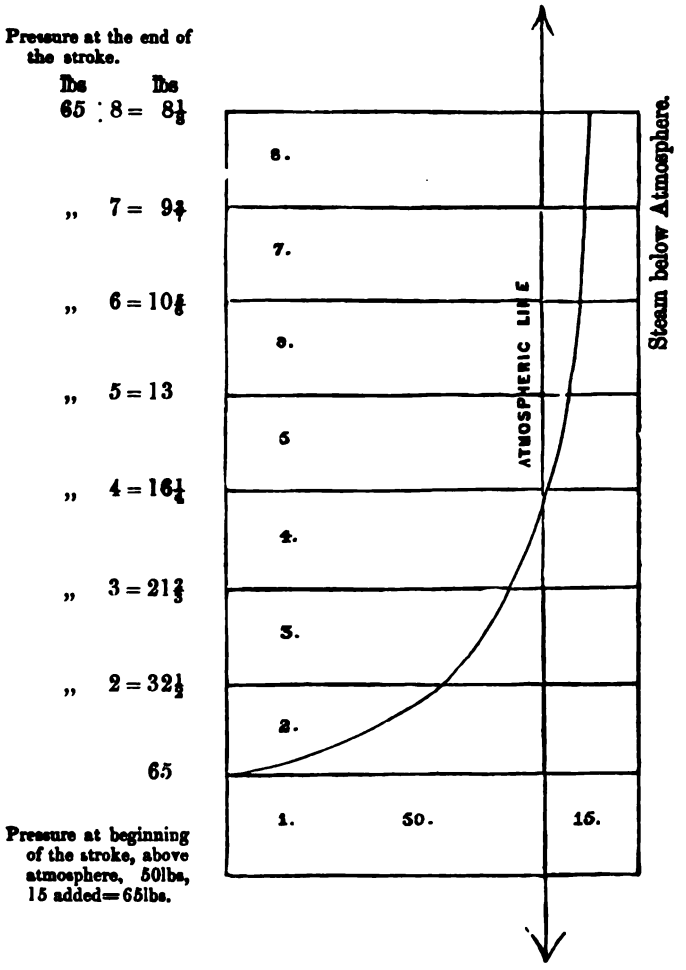
throughout, we obtain additional power by expansion, —indeed, upwards of three times the power—or as 200 is to 65.

The annexed figure illustrates the expansion of steam in the cylinder, and forms a mode whereby to ascertain the pressure at any portion of the stroke. In the figure the steam is represented at the commencement as being at 65lbs on the piston, cut off at one-eighth the stroke. The figures 1, 2, 3, 4, 5, 6, 7, and 8, are the numbered divisions of the cylinder. To ascertain the pressure when the piston has travelled either one-fourth or one-third, or any other portion of the stroke, the pressure in the first division must be divided by the number of divisions, or portions, whose pressure is required to be known. Thus, if the pressure be required when the piston has travelled half the length of the cylinder, we must divide by four, the piston having travelled four parts out of the eight into which the cylinder is divided. So also with each division or number of divisions. Where the expansions are either less or more, the cylinder must be divided accordingly into the same number of parts as there are expansions.

For example: steam at 20lbs above the atmospheric pressure, cut off at one-third of the stroke, will be, at the end of the stroke, 11⅔; thus, 20lbs of steam and 15lbs atmospheric pressure equals 35lbs cut off at one-third—is $3 \div 35 = 11{\cdot}2$, or nearly 4lbs below atmosphere. If a High-pressure Engine, the pressure of the atmosphere must be added in the same way. Example: 80lbs cut off at one-sixth the length of the cylinder: 80 added to 15 equals 95; 6 in $95 = 15{\cdot}5$. The steam in this case will have expanded down to the pressure of the atmosphere within five-sixths of a

ILLUSTRATION OF EXPANSION.

Diagram No. 70.



ound, and therefore will have been practically used p in a Non-condensing Engine before it is allowed to scape. In a Condensing Engine, the 15·5lbs would,

in practice, expand down to 5lbs or 10lbs below atmosphere: the difference being power lost in a Non-condensing Engine.

In using steam of high-pressure, another advantage is obtained, insomuch as it requires proportionately less fuel for the generation of increased high-pressure steam. The cost of the raw material, or fuel, for steam at various pressures will hereafter be shewn, and the saving effected by generating and working with steam at high-pressure will be noted.

Steam on	Quantity of steam used.	Pressure of steam above atmosphere.	Pressure of steam with the atmosphere.	Power obtained.	Pressure of steam at the end of the stroke.
Full length	100	80lbs	95lbs	100	95lbs
Cut off at $\frac{7}{8}$	$87\frac{1}{2}$	...	...	97	83
Cut off at $\frac{3}{4}$	75	...	...	95	71
Cut off at $\frac{5}{8}$	$62\frac{1}{2}$	...	...	92	59
Cut off at $\frac{1}{2}$	50	...	...	84	$47\frac{1}{2}$
Cut off at $\frac{3}{8}$	$37\frac{1}{2}$	...	...	71	$31\frac{1}{2}$
Cut off at $\frac{1}{4}$	25	...	...	60	$23\frac{1}{2}$
Cut off at $\frac{1}{8}$	$12\frac{1}{2}$	...	...	37	$11\frac{3}{4}$

The above table shews the quantity of steam used when worked without expansion, and the power obtained; also the quantity when worked expansively, varying from $\frac{7}{8}$ to $\frac{1}{8}$ the cut off, and the pressure of the steam at the termination of the stroke. It will be observed that in proportion as the steam is expanded to the greatest limit, so is the saving:—the principle of expansion being a *saving* and not a gain. But the whole of the steam is made available when expansion is carried to its full extent. Thus, if steam at 60lbs, or any other pressure, be brought upon the

piston, and cut off at a point to enable it to expand to the lowest practical limit, the most will have been made of it, although the expansion has been effected in one cylinder.

When the steam passes through a number of cylinders, there is a loss by condensation and friction, particularly if the pressure be high. The conducting properties of the metal rob the steam of its heat in proportion to the difference of the temperature. Hence the necessity of clothing high-pressure cylinders and pipes with felt, or other non-conducting substance, to prevent the absorption of the caloric; or of casing them, keeping steam in the casings at the pressure of the boiler. The higher the temperature at which the cylinders of Steam Engines can be maintained, the better.

GENERAL OBSERVATIONS ON THE COMPOUNDING OF STEAM ENGINES.

THE compounding of Steam Engines has for its object the using of high-pressure steam to the greatest advantage.

The principle was first introduced by HORNBLOWER, in 1781; but, from the prejudices then existing against high-pressure steam, which had their origin in the danger then associated with the great power sought to be attained, the principle made comparatively little way. The danger, however, was not with the pressure, but in the form of boilers, in the construction of which an incorrect principle was then, and still has been, generally followed. It is this which has mainly retarded the employment of high-pressure steam.

HORNBLOWER first introduced the system of two cylinders for the purpose of expansion; and WOOLFE followed with an improved boiler. Thus was laid the ground-work for working high-pressure steam with economy and safety; but when we consider the present construction of boilers for Stationary Engines, we are forced to acknowledge that we have made but slow progress in the real development of steam power by the employment of high-pressure steam.

The benefit of high-pressure steam is fully shewn in the case of Locomotive Engines, which work at a

pressure of from 100lbs to 150lbs to the square inch, and are quite as manageable and safe as any Low-pressure Land Engine. When the simple form of boiler for Stationary Engines is better understood and put in practice,—that form which unites the power of greatest resistance with the greatest available amount of heating surface,—we shall then, but not until then, reap the full advantage of high-pressure steam.

HORNBLOWER's method of using the steam twice was very simple. The first, or high-pressure cylinder, which the steam first entered, was placed close to the ordinary cylinder of a Condensing Engine. The diameter of the high-pressure cylinder was much less than that of the condensing cylinder. The steam from the boiler first acted upon the small cylinder, passed thence to the large one, and from that to the condenser, where it was condensed in the usual manner. The principle, or action, was thus described by HORNBLOWER, in his own specification: "I employ the steam, after it has acted in the first vessel, to operate a second time in the other, which I do by connecting the vessels together, and forming proper channels and apertures, whereby the steam shall occasionally go in and out of the vessels."

HORNBLOWER's specification bears date July, 1781. It is now, therefore, more than eighty years since the principle of compounding Steam Engines was first enunciated and put in practice.

As all other methods of compounding Engines are but a variation in plan, and not of principle, it will not be out of place to explain more fully the principle of the High and Low-pressure Engines, as set forth in HORNBLOWER's specifiations.

Suppose two cylinders, one high and one low-

with the exception of the 8lbs which remain to be condensed. But it would not be so in the case of the equal diameter cylinders. The steam in that case could not be expanded, but would have to be condensed at the pressure it entered the first cylinder, and this would be a loss of power. The power of the Engine with the equal diameter cylinders would only be 30, while the power of the unequal diameter cylinders would be 70—with the same quantity and pressure of steam in both cases.

Column 1	2		3		4	5
Inches 1	27¼	added to	169¼	equals	196½	360
„ 2	37½	„	135	„	172½	180
„ 3	43	„	102½	„	145½	120
„ 4	46¼	„	82¾	„	129	90
„ 5	48½	„	69½	„	118	72
„ 6	50	„	60	„	110	60
					871½	822

It has long been known that the power derived by expanding a given volume of steam in two cylinders amounts to the same as an equal number of expansions effected in one cylinder. When the pressure is not too great, and the Engine is sufficiently strong and runs quickly, it is preferable and less complicated to expand in one cylinder; but where the steam is at an extremely high pressure, great advantage is obtained by employing two cylinders—it being essential, however, that the high-pressure cylinder be less in area than the low-pressure one, and the steam on for the full length of the stroke. Steady turning will

in such case be obtained, and a less fly-wheel be required.

The table on the preceding page is calculated for each inch of the stroke, with a pressure in the boiler of 60lbs per square inch. The small cylinder of the Compound Engine is assumed to be of one inch area, and the large one of six inches area, with a six-inch stroke; consequently, the steam cut off at one-sixth of the large cylinder will be equal to the whole area or full contents of the small high-pressure cylinder.

Column 1 expresses the number of inches the piston has moved; column 2, the difference of pressure on the piston for each inch of the stroke; column 3 shews the power operating upon the large piston at each inch of the stroke; column 4, the sum total of the power exerted by both pistons; and column 5 exhibits the force per inch, when the same volume of steam is expanded in one cylinder only, being the same number of expansions in the single cylinder as is obtained by the difference in the dimensions of the compound cylinders.

In glancing down columns 2 and 3, it will be seen that the small cylinder equalizes the power of the Engine at the commencement of the stroke, and its restoration at the termination. The result of expansion in the two cylinders will be the difference of the power exerted on the piston between the commencement and the termination of the stroke, which is about two to one with the Compound Engine; while the Single Engine exhibits a difference of pressure upon the piston of six to one. At the same time, the totals at the bottom shew the total power to be nearly equal. This is a most important object gained—nearly equal strain upon the Engine and the equaliza-

tion of power, without the incumbrance of an extra heavy fly-wheel to produce steady motion : a fact very important to manufacturers, because it involves much less wear and tear.

WATT saw the value of working steam expansively; but the method of constructing boilers and the deficient workmanship of his day prevented him from applying the principle. This can be now effected with perfect safety. All he left to be accomplished was the introduction of proper means to furnish steam of high-pressure with safety.

Messrs. JAMES AND JOHN ROBERTON, of Glasgow, patented a plan of compounding Steam Engines, in the month of August, 1800. Their principle of using the steam was precisely the same as that of HORNBLOWER, introduced nearly twenty years before. ROBERTONS' cylinders, however, were differently placed—they fixing the high-pressure cylinder at one end of the beam, and the low-pressure cylinder at the other end, the same as in the Double-cylinder Engine of the present day, commonly called the MCNAUGHT. In reflecting on this, we cannot but remark how possible it is for mechanical science to degenerate, and be again brought to light by superior tacticians, while the original propounders of the principle are lost sight of.

Messrs. ROBERTON, in their specifications, which are very long, explain the working of their Engine thus :—"The steam, therefore, which remains above the small piston and below the large piston, will force the pistons forward in proportion to the steam's density, and the difference of the areas of the pistons; that is, a force in proportion to the density of the steam and the excess of the area of the large piston

to that of the small one." The application of the two cylinders is thus described :—"Our plan consists of two cylinders, a lesser and a larger, the piston-rods of which are connected by a toothed wheel, or beam, placed between them, which gives motion to the machinery by a crank, or otherwise. By this method the piston of one cylinder *ascends* while the other *descends*." Thus we see that what is now being done with a Compound Engine, with a cylinder under each end of the beam, was fully understood sixty-two years ago. It is now over eighty years since the first Compound Engine was introduced, and sixty-two since a high-pressure cylinder was placed at the other end of the beam.

In another part of this work examples will be given of the compounding of Beam Engines; and if the reader will keep steadily in view the principle and the object of using two cylinders, he will soon be satisfied that the principle of compounding, in many cases, has been injudiciously applied, where the high-pressure cylinder has been made too large, and comparatively low-pressure steam used. Had a better knowledge of the principles of expansion prevailed, a great number of Engines which have been compounded would have been left untouched, considering the pressures at which they are worked. To some, this may appear to be paradoxical; but the examples hereafter adduced will elucidate our meaning.

WOOLFE, also, in 1804, patented a plan of compounding Steam Engines. His principle was the same as that of HORNBLOWER and the ROBERTONS, excepting that he proposed to use steam at much higher pressures than either of the former dared to propose. WOOLFE also devised a plan of small diameter steam

boilers for the generation of steam; his plan shewing much judiciousness in the separation of his water and steam into small quantities, thereby enabling him to use high-pressure steam with perfect safety—a point which is not now cared for as it ought to be; for it is truly awful to contemplate the force pent up within large boilers from six to ten feet diameter, and from twenty to forty feet in length. No good reason can be assigned for the use of such large engines of destruction; for the quantity of metal contained in these large and unsafe structures, would produce boilers of many times the strength, and of double the power, with a less expenditure of fuel, were they only constructed in a proper form—the simple form of greatest resistance.

We have next to consider separate High-pressure Engines, connected, by gearing or otherwise, to the Low-pressure, or Condensing Engines. These High-pressure Engines are often worked horizontally; and two are sometimes coupled, so as to work at right angles to each other. The principle of using the steam twice in these Compound Engines is the same as HORNBLOWER'S, with this exception—his was a single high-pressure cylinder, of an equal number of strokes with the piston of the condensing cylinder, and both cylinders were placed together; so that whatever pressure there was upon the piston of the condensing cylinder, an equal back-pressure was upon the high-pressure piston. This is not so where two high-pressure cylinders are used. The strokes of the latter are not equal with the strokes of the low-pressure piston; therefore the exhaust steam has to be compressed, or else expanded into a large space, previous to entering the low-pressure cylinder. In either case

a loss ensues from the extra back-pressure on the high-pressure piston, or from a decreased pressure upon the piston of the low-pressure cylinder, from the steam having been suffered to expand in the large space betwixt the two Engines. Double High-pressure Non-condensing Engines have generally short strokes; and although they may apparently work well for a time, the action and re-action will ultimately affect them. The power lost in the numerous reversals of the piston and connecting-rods is a serious drawback from the aggregate power; and the great friction and condensation of the steam with the extra wear and tear, involve a considerable loss, compared with the simpler principle of expanding the steam in one cylinder.

There are other modes of compounding, such as having two Beam Engines connected together, the first being a non-condensing one, and the other a condensing one. The steam from the Non-condensing Engine is allowed to exhaust into a large vessel, and there to expand. Then from this large vessel the expanded steam passes to supply the Condensing Engine. Thus the steam is used twice—first in the high-pressure, and then,—when the steam is already expanded,—in the low-pressure: an arrangement which only proves how little the constructors understood the principles of expansion and the compounding of Engines. Allowing the steam to expand in a separate vessel without giving out power, instead of [illegible] once being made available on the piston of the [illegible] densing cylinder, while there w[illegible] ower in the [illegible] and taken in combination [illegible] he great [illegible] exposing the steam to a l[illegible] nount o[illegible] surface, must necessarily resu[illegible] eat loss

COMPOUNDING BEAM ENGINES BY A STEAM CYLINDER AT EACH END OF THE BEAM.

The method of compounding Steam Engines with a steam cylinder at each end of the beam, was first introduced and patented in 1800, by Messrs. J. AND J. ROBERTON, of Glasgow, as before explained; and the method now adopted is only a variation of their plan, consisting of a high-pressure cylinder placed half-way between the centre of the beam and the crank, so that the traverse of the high-pressure piston shall equal half of the stroke of the low-pressure piston.

The plan of using two cylinders is fully set forth in Messrs. ROBERTONS' specifications. It has lately been re-patented, and introduced as a good method of compounding Steam Engines. Of the effect of that method we here present an example. Were that example a solitary case, we should not dwell on this part of the subject; but knowing that this particular method of compounding Engines has attained a position not warranted by principle nor improved practice, we deem it necessary to go somewhat into detail; and in illustration of the method, present diagram No. 71, which was taken from the low-pressure cylinder of a Compound Engine, at the Paper Manufactory of Messrs. POTTER AND CO., Darwen, near Blackburn. The low-pressure cylinder of the Engine is thirty-seven inches in diameter, the length of the stroke six feet, working twenty-six strokes per minute; the average pressure upon the piston was 11lbs per square inch; the power 111 horse, as shewn by the diagram.

Diagram No. 71.

ıken from the Top of a Low-pressure Cylinder of a Compound Engine.

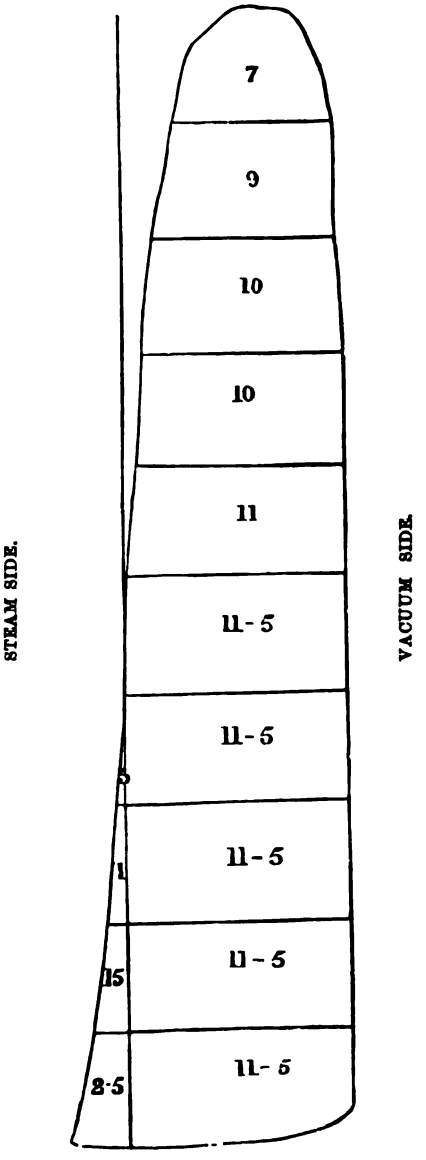
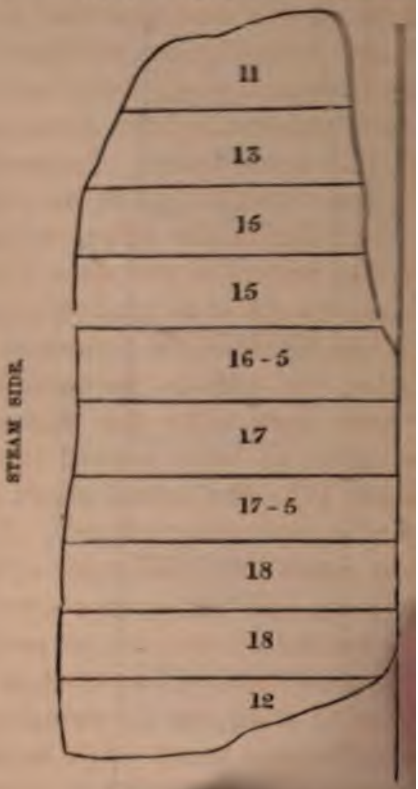


Diagram No. 72 was taken from
cylinder at the other end of the be
of that cylinder is thirty-three inc

DIAGRAM No. 72

Taken from the Top of a High-pressure Cylinder



feet stroke, working ix strok
The average pressure u iston
square inch. Power of
total horse power given

piston for the steam to operate upon, and by dispensing with the back-pressure of the present mode of working, arising from the disproportion of the high-pressure to the low-pressure cylinder, as explained at page 220. Again: suppose that the steam was admitted on to each piston at 30lbs pressure per square inch, a higher beneficial effect would be produced in the ratio of the increased pressure, by cutting off the steam so as to expand it to its lowest possible pressure: that is a proportionately increased amount of saving both in fuel and water would be the result; and the latter is sometimes as valuable as the former. By this example we are taught that great advantage must arise from the conversion of the high-pressure cylinders of Compound Beam Engines, where they are too large in proportion to the low-pressure cylinder, into condensing cylinders. It is a fallacy to suppose that any benefit can arise from compounding Steam Engines unless the pressure be great and a sensible difference in area, or the contents between the two cylinders, can be obtained—so that the high-pressure cylinder shall be from four to ten times less area than the area of the condensing cylinder, in accordance with the pressure; for if the pressure be great, the high-pressure cylinder will require to be proportionately less. The steam being divided into two cylinders, one at each end of the beam, there will be less strain upon the foundation and beam centres than if the steam was worked expansively in one cylinder to give out the same amount of power. By the use of high-pressure steam through two cylinders attached to one beam, in that proportion is there an increased strain upon the parts of the Engine, according to the increased power from the increased pressure, which at

all times should be avoided if possible; for the longer an Engine works the weaker it becomes. An Engine may be quite safe when new, working out a given power: but by continued use the metal, from constant action and re-action, becomes granulated, and less able to resist strain and concussion; and this result will be accelerated by over-tension.

In many cases of compounding it is better to apply a separate High-pressure Engine independently of the Low-pressure Engine, because the power of the high-pressure has not to go through the Low-pressure Engine, as is the case in compounding with two cylinders under one beam. The two Engines should work stroke for stroke, and as near to each other as possible: then the full effect of the steam will be gained. Where the cylinders are so far apart as at each end of the beam, the steam loses a considerable portion of its pressure by condensation and expansion in the pipes and passages betwixt the two cylinders.

It cannot be too often enjoined that in all cases of compounding, the high-pressure cylinder must be sufficiently small in diameter in proportion to the condensing cylinder; and if an increase of power is required, it must be obtained by increased pressure of steam. Improvements in the working and power of Engines have doubtlessly been effected by applying a second cylinder at the other end of the beam, and using higher pressure steam; but had the valves been properly set, and the Engines been worked with the same pressure of steam as when compounded, more power would have been derived by expansion from one cylinder than from the two, with less expenditure of fuel and less wear and tear. In most cases the advantages attributed to Compounded Engines are

derived from expanded high-pressure steam; and this expansion can often be better accomplished with a single cylinder than by the mode generally adopted, unless the pressure of the steam be great—in which case two cylinders may be advantageously applied.

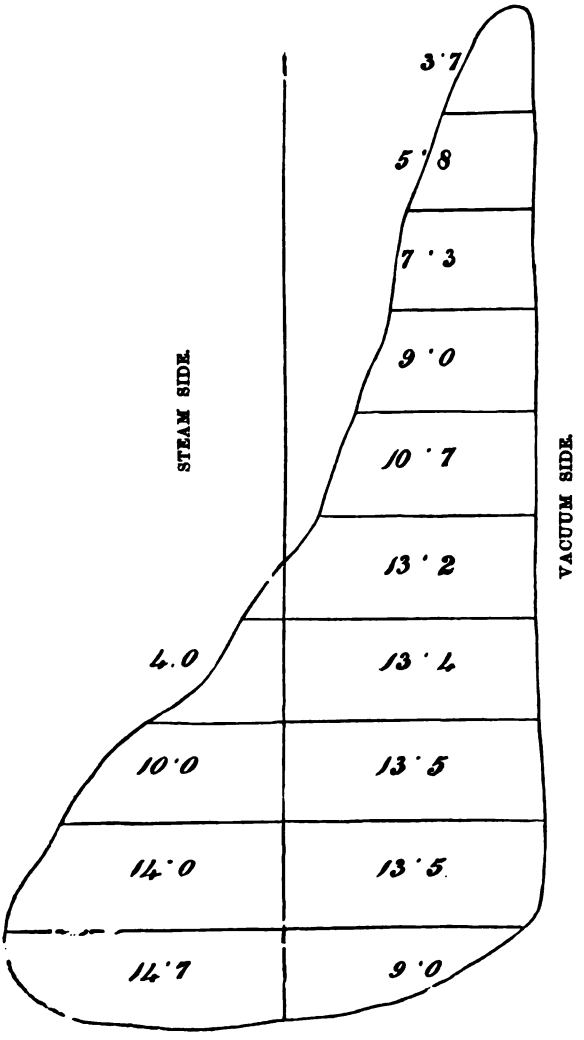
Take for example the case of Messrs. RODGETT AND BRIERLEY, of Blackburn. This firm have three Engines, which formerly required six boilers to drive them, at a pressure of 20lbs per square inch, consuming 90 tons of coal per week. The valves of these Engines were set so as to allow of expansion, and two new boilers, to work at 60lbs pressure, were substituted for the six at 20lbs pressure. The result of the alteration was a reduction in the consumption of fuel of from 90 to 45 tons per week—or a saving of fifty per cent. After the alteration the Engines worked much better. These decided improvements were effected without the aid of additional cylinders. Increased pressure of steam, valves properly set, and expanding the steam in the single cylinders, produced the desired effect.

Had these Engines been compounded, there is not the least doubt but that "the compounding" would, as usual, have received all the credit which resulted from steam at increased pressure worked expansively. An examination of the principle of compounding Engines will shew to an attentive observer that in many cases the addition of a second cylinder, with the steam used at the present pressures, entails a loss and not a gain. Were the same steam at the same pressure worked expansively in one cylinder, better results in most instances would be obtained, with less friction and condensation from there being fewer parts to the Engine—all additions to which absorb power.

Diagram No. 73 was taken from one of the low-pressure cylinders of a pair of Beam Engines, "McNaughted," belonging to Messrs. T. NIELD AND

DIAGRAM No. 73.

Taken from the Top of a Low-pressure Cylinder.



Son, of Ashton. The cylinder from which this diagram was taken is 44 inches in diameter. There were four cylinders altogether—two high and two low-pressure. They worked for a considerable time connected in the usual way. The steam from the boiler entered the first, or high-pressure cylinder, and, after completing the stroke, it exhausted into the low-pressure cylinders at the other end of the beam, and expanded to its fullest limit, according to the difference of the capacities and contents of the two cylinders. It was then condensed in the usual way. There were four cylinders with their valves, pipes, boxes, and a great amount of cool surface for the steam to act upon in passing through the Engines. There was also a large quantity of extra metal to be moved about, and friction to be overcome, which, taken altogether, would no doubt be considerable. After a while, finding that other parties with Engines not compounded were using less fuel for the same amount of power given out, the proprietors decided that two of the high-pressure and one of the low-pressure cylinders should be disconnected, and the valves of the remaining low-pressure cylinder set to work with steam direct from the boiler. This was accordingly done, and diagram No. 73 was taken after the alteration. On an examination of the diagram, it will be perceived that the steam has expanded to 10lbs below atmosphere at the end of the stroke. Taking the diagram altogether, it is an excellent one. The valves are well set. The result of the change was a saving of 44 tons of coal per month for the same amount of work performed—rather astonishing to those who fancied that Compounded Engines in all cases must result in a saving of fuel. In this case, under the circumstances, compounding was a loss.

Having now given several examples of the present "fashionable" mode of compounding Engines by the addition of a second cylinder; and having adduced facts to prove that in many cases where this plan has been adopted better results could have been obtained by more simple means, we now come to speak of the particular plan itself, protected, as it is pretended to have been, by patent.

We have before explained that the plan of compounding Engines by the use of a second cylinder placed at the other end of the beam, or otherwise connected with the original cylinder of the Engine, was patented in 1800, by Messrs. J. AND J. ROBERTON, of Glasgow; and extracts from their specification will be found at page 224.

In describing that plan, we stated that it had been *re-patented*, of which statement we now offer proof.

On the 10th of December, 1845, a patent was granted to WILLIAM MCNAUGHT, of Glasgow, for "Certain Improvements in Steam Engines,"* which improvements are described in the following extract from the specification of the said patent:—

"It will be seen that my improvements consist in the application of a non-condensing cylinder to the kind or description of Condensing or Low-pressure Beam Engines presently used; and attaching or connecting such cylinder to the opposite end of the working beam from that on which the condensing cylinder is connected: thereby causing the steam, after being used in the usual way in the non-condensing cylinder, to be used for impelling the piston of the condensing cylinder, after which it escapes into the condenser in the usual way."

* This patent expired in 1859.

The claim made in this specification is as follows:—"I claim as my invention the application of a non-condensing cylinder for the purposes hereinbefore set forth," * * * * "by applying or connecting the non-condensing cylinder at any convenient part of the opposite end of the beam from that on which the low-pressure cylinder is attached; and any such application would equally be embraced by or comprehended under my invention; and is to be understood as being claimed by me accordingly."

After considering the foregoing, let the reader again refer to the extracts from the specification of the ROBERTONS inserted at page 224, and compare the claim then made with the claim advanced in the patent of 1845, which has now expired.

Accompanying the specification of the patent of 1800, are several drawings, or plans, shewing how to compound by means of a high-pressure cylinder placed at the opposite end of the beam to the condensing cylinder, or by other modes of connection. An examination of these plans will shew conclusively, that the claim made by Mr. MCNAUGHT, in his specification of 1845, is precisely the mode claimed by the ROBERTONS forty-five years before.

When describing diagrams 71 and 72,—pages 229 and 230,—we shewed by reasoning which Engineers will admit to be conclusive, that the conversion of the high-pressure cylinder of the Compounded Engine into a condensing cylinder, using the one condenser and the one air-pump for both cylinders, would have given fifty-five horse power more, with ten per cent. less steam, than was obtained by the method of compounding adopted. This idea is not a new one to the writer. Years ago, and in reference to those very

Engines, Nos. 68 and 69, it was set forth in a report to Messrs. POTTER AND Co., and the plan of working the two cylinders as condensing cylinders with one condenser and air-pump, was proposed. Since then other Engineers have evidently begun to doubt the soundness of the principle on which Engines are generally compounded—the "fashionable plan" having attained a position not warranted either by principle or sound practice. In proof of this improved feeling amongst Engineers, we may adduce the fact that in June, 1855, Mr. JONATHAN MUSGRAVE, of the firm of MUSGRAVE AND SON, Engineers, Bolton-le-Moors, took out a patent* for the application of a second condensing cylinder to Steam Engines, both cylinders being worked by one condenser and one air-pump, as the following extract from Mr. MUSGRAVE's specification will shew :—

"My invention consists in the application to Condensing Engines of the ordinary construction of a second condensing cylinder, the piston-rod of which is connected to the beam in any convenient position on the connecting-rod side of the beam centre. In working my improved Steam Engine, each cylinder would be supplied with steam of the same pressure; and the cylinders, instead of being in connection with each other, as in ordinary Compound Engines, are each in connection with a condenser, into which the steam, when it has acted on the piston, is conveyed in the ordinary manner. In case the air-pump and condenser of the Steam Engine are not sufficiently large when the second cylinder is applied, I propose to add a second air-pump and condenser, or enlarge those

* This patent expired in the year 1858, not being renewed after the first three years.

originally employed: the object of my invention being to increase the working power of a Steam Engine without increasing the pressure of the steam employed."

Mr. MUSGRAVE here enunciates the proper principle on which to compound Beam Engines, so as to work advantageously and economically with the ordinary pressure of steam; and when the present "fashion" of compounding has in some degree abated, and the true principle become more clearly developed in practice, no doubt a change in general feeling on the subject will take place, to the great advantage of parties employing Compound Beam Engines.

Since the publication of this work, and the publicity therein given to the foregoing extract from Mr. MUSGRAVE's specification, Mr. WM. MCNAUGHT has taken out a new patent for compounding Steam Engines, which patent bears date February 25th, 1859.

The following is an extract from the specification upon which the patent was granted:—

"First, my improvement consists in applying to the present form of Engine known as 'MCNAUGHT's Double Cylinder Engine,' (and patented by me, 10th December, 1845), a cylinder or cylinders connected either to the crank-shaft of the Engine, or to the Engine through the medium of gearing, the steam being supplied to this cylinder or cylinders in the usual way, and thence pass to the condenser or condensers of the Engine or Engines."

It thus appears that after the expiration of the patent taken out in 1845, Mr. MCNAUGHT has dis-

covered that which other people have had in practice for years, and which was well known to the merest tyro in Engineering—viz., that adding more cylinders to a Steam Engine, and working the steam expansively, will result in an increase of power!

There are "claims" in this new patent of 1859 that are too absurd even for notice.

On the 5th of October, 1860, Mr. McNaught obtained another patent for "Certain Improvements in Steam Engines."

The following is an extract from the specification upon which this additional patent was granted:—

"First, I claim the connection of one or more cylinders or Engines by gearing to a Condensing Engine or Engines, and passing the exhaust steam of these cylinders into the condenser or condensers of the Condensing Engines."

The 1860 patent is, in the particular pointed out, the same as the 1859 patent—both of them "claiming" that which had been set forth and advocated in this work throughout the second and third editions. Numerous Engines are working, and have been for years, according to the plans set forth in these two specifications. Is it not rather surprising that parties professing to be leading Engineers should be so far behind in a knowledge of what other Engineers are doing daily?

This system of re-patenting known plans and principles has now become so extensive and so annoying, that it is high time some better mode of granting patents, and of protecting the public from the "claims" of spurious patentees, should be adopted, than that which obtains. Under such new mode the legitimate inventor should be provided with a

summary mode of establishing a fair claim to an invention, without the ruinous expense and the uncertainty of the present practice. Under the present system the humble inventor is often deprived of his invention because he has not the means to enter into a tedious and complicated action-at-law. Two or more common-sense practical men could decide such cases with far greater facility, and with a far greater chance of justice to all the parties concerned, than is possible under the present ruinous, round-about, and unsatisfactory mode.

There is scarcely any portion of the Steam Engine where the makers differ so widely in their proportions of the cylinders working with steam at the same pressure, as they do in Compound Engines. This can only be accounted for by the builders not understanding the principles of expansion. Some contend that the high-pressure cylinder should be from one-third to one-half the capacity of the condensing cylinder; and the steam cut off in the high-pressure cylinder. At pages 220 and 221 this principle is fully explained. The next two examples will be in illustration of the proportion which the high-pressure cylinder should bear to the low-pressure cylinder.

SINGLE CYLINDER HIGH-PRESSURE ENGINE CONNECTED, AND WORKING STROKE FOR STROKE, WITH A CONDENSING ENGINE.

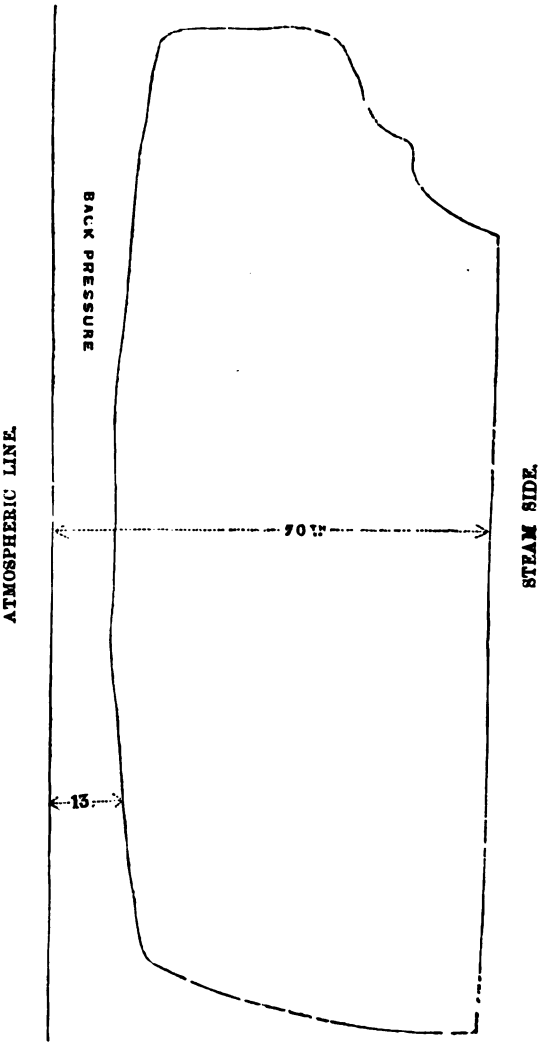
We next adduce examples of the class of Compounded Engines described in our heading. The diagrams which follow were taken from two Engines belonging to Messrs. GREAVES, of Oldham. The pressure of steam in the boiler was 90lbs per square inch, generated in one of "HOPKINSON's Patent Safety Transverse Boilers." The pressure of the steam upon the piston of the High-pressure Engine, —from which diagram No. 74 was taken,—was 70lbs per square inch above the atmosphere. The steam was cut off at four-fifths the length of the stroke. The average back-pressure upon the high-pressure piston, as shewn by the diagram, was 13lbs per square inch, leaving an available pressure upon the high-pressure piston of 57lbs per square inch. The diameter of the high-pressure cylinder is 12½ inches, or an area of 122¾ inches. The stroke is six feet, working 24½ strokes per minute, or 294 feet in the same period. The cylinder was placed in a horizontal position, close to the condensing cylinder. The steam from the high-pressure cylinder passed into the side-pipes of the large condensing cylinder, by means of a small exhaust-pipe, direct to the piston, without having lost much of its temperature in passing from one to the other,—a point not to be lost sight of in the construction and arrangement of high and low-pressure cylinders when they have to work with each other.

Diagram No. 75 was taken from the condensing cylinder supplied by the steam from the High-

pressure Engine. The steam at the commencement of the stroke—as shewn by the diagram—is 12lbs

Diagram No. 74.

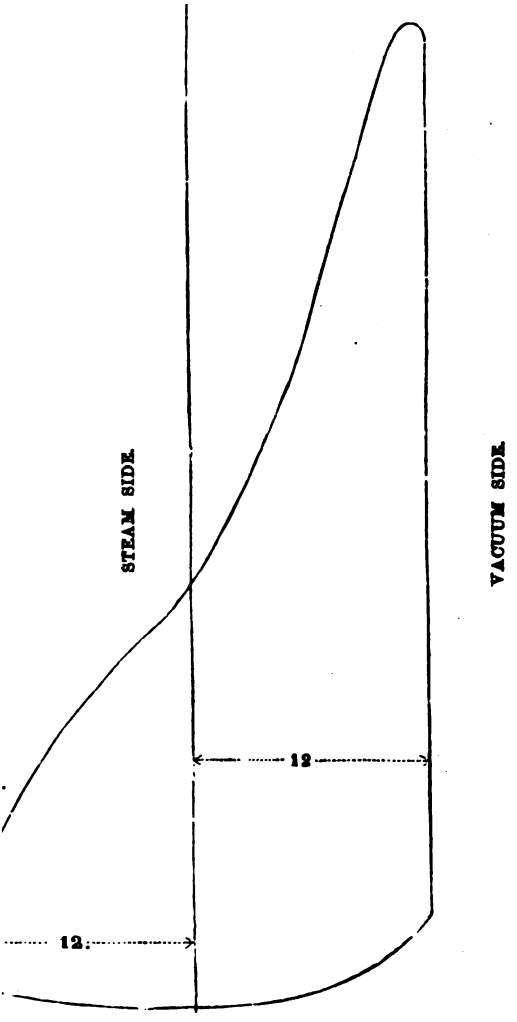
Taken from the Horizontal High-pressure Cylinder of a Compound Engine.



ıt one-fourth the length of the stroke, nding in the cylinder to 9lbs below the

DIAGRAM No. 75.

m the Top of the Condensing Cylinder of a Compound Engine.



atmosphere—leaving only 6lbs to condense at the end of the stroke : thus shewing that the 85lbs steam was used up to within 6lbs ; or, in other words, there was only a loss of 6lbs in 85lbs—a very small loss indeed, when compared with ordinary working. The low-pressure cylinder is 35 inches diameter, or 963 inches area ; being nearly *eight times the area* or capacity of the high-pressure cylinder, with which the former works stroke for stroke. Here high-pressure steam is carried out to a profitable extent. The action of the steam at an equal pressure for nearly the full length of the stroke upon the high-pressure piston keeps the strain and power equal—each Engine being connected to the first shaft. The power of the high-pressure cylinder does not go through the Low-pressure Engine, as is the case when two cylinders are placed under one beam. The whole case presents an example of a Compounded Engine worthy of being followed. It is an illustration of the best mode of compounding an old Beam Engine, when sufficient pressure of steam can be obtained.

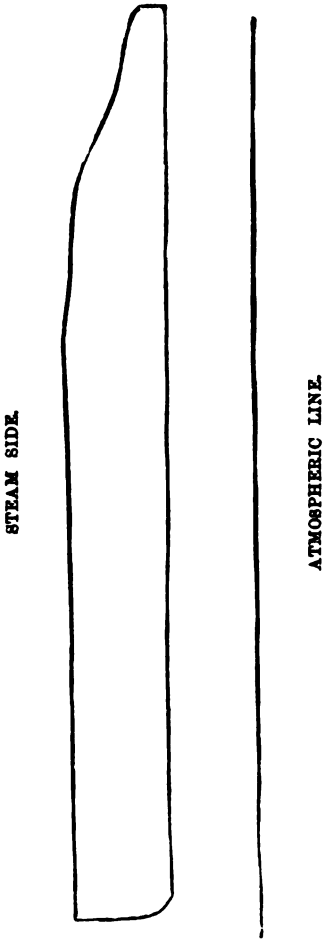
The next diagrams are from a Compound Engine belonging to Messrs. SUGDEN AND SONS, Corn Millers, Brighouse. The pressure in the boiler was 30lbs per square inch. No. 76 diagram was taken from the high-pressure cylinder. The pressure upon the piston was 28lbs per square inch, and the back-pressure 14lbs per square inch. The diameter of the cylinder is 23 inches, or 415½ inches area. The piston travels the same number of feet per minute as the condensing piston. The average available pressure upon the high-pressure piston was, therefore, only 14lbs to the square inch.

Diagram No. 77 was taken from the low-pressure

ɜ same Compound Engine. This
inches in diameter. The average
ɜam upon the piston of the Low-
ı was 12lbs per square inch above the

DIAGRAM No. 76.

High-pressure Cylinder of a Compound Engine.



STEAM SIDE

atmosphere, leaving 27lbs of steam to condense at the end of the stroke. This involved a loss of 27 in 43, leaving only 16lbs of the 43 available for work.

The difference in the working of the two Compound Engines last considered is remarkable. The first sustained only a loss of steam of 6 in 85, and the other a loss of 27 in 43! In the last case, it will be observed that the diameter of the high-pressure cylinder is 23 inches, and the low-pressure cylinder only 22 inches; the high-pressure *having an excess of* $35\frac{1}{4}$ *inches in area over the low-pressure piston!* The back-pressure on the high-pressure piston being 14lbs, and the pressure on the low-pressure piston only 12lbs, the high-pressure had a preponderance of power of two pounds per square inch, and $35\frac{1}{4}$ inches greater area! Had the steam from the boiler been stopped at the point where the steam was exhausting from the high-pressure into the low-pressure cylinder, the Engine would have started back with the force of the back-pressure upon the high-pressure piston! This back-pressure was only overcome by the *full* force of the steam from the boiler acting on the other side of the high-pressure piston.

This very serious back-pressure caused a great "back-lash" of the gearing, which was found to be destructive to the machinery. To obviate this as much as possible, the Engineer placed a weighted escape-valve between the two cylinders, that the surplus steam which could not be forced through the Condensing Engine might thereby escape into the chimney—thereby entailing a still further loss than the 27 in 43! The High-pressure Engine was also provided with an expansion-valve to cut off at one-third or any portion of the length of the stroke. But

this was found to be useless: for when the steam was cut off, and expanded in the high-pressure cylinder previous to being admitted to the condensing cylinder, the pressure upon the condensing piston *being less* than the back-pressure upon the larger area of the high-pressure piston, the latter had the greatest power; and the effect was that the exhaust steam of the high-pressure cylinder *absorbed*, instead of giving out, power. Had the exhaust steam from the High-pressure Engine been condensed—or, in other words, had a vacuum been made within the larger area cylinder, and that Engine been worked alone, more power would have been given out by that one Engine than with the two Engines compounded in the manner described.

Expansion of steam is a subject which is not well understood; for many believe that, under such circumstances as have been detailed, by cutting off the steam in the high-pressure cylinder, and working it expansively, they accomplish a similar effect as by using a small cylinder. A little reflection, however, will shew that this cannot be; for the only gain in working two cylinders with the same steam arises from the difference of the areas. Where this is attended to, according to the pressure of steam, so will that steam be used up with the least expenditure of fuel. The great object, therefore, in constructing Compound Engines should be to have the high-pressure cylinder of such size—that is, so proportionately small in dimensions—that the steam may be on for nearly the whole length of the stroke of the high-pressure cylinder; and no expansion should take place, if possible, until the steam is admitted on to the large piston in the condensing cylinder.

In the construction and mode of working of the Engines last described the proprietors had placed themselves in the hands of one of the largest Engineering establishments in this locality, in whom they had every confidence; and though the defects of this mode of compounding were pointed out to them, and a plan for remedying the injurious action and consequent loss of power was laid before that firm, they would neither listen to the suggestions nor effect the alterations proposed.

Compare the principle of compounding in this latter case with the one adopted in the case of the Messrs. GREAVES; the latter having the high-pressure cylinder of one-eighth the area of the condensing cylinder; the other with the high-pressure cylinder one-ninth *larger* than the condensing cylinder! This great difference is a proof that the true principle of compounding Engines was not understood by the constructors of the Engines belonging to Messrs. SUGDEN AND SONS. The intolerant spirit which is too often engendered by the success of large firms, would, were the parties possessed of the requisite power, render principle subservient to deficient knowledge. Luckily this is beyond their reach; and however firm may be the hold which great repute may obtain, ultimately reason and truth will prevail over mere presumption. Success in business does not always proceed from talent; for in many establishments a man of tact is of far more importance to commercial success than a competent and well-informed Engineer distinguished by that modesty and absence of presumption with which true knowledge is always accompanied.

The Engines last referred to worked about three years in the state described; and during that period

several pairs of driving-wheels were worn out. The teeth were not cut away at the front, but at the back, as may readily be imagined from the great "back-lash" sustained, the High-pressure Engine having a tendency to start back at each reversal of the stroke. Another result was a great destruction of the small wheels, the spindles, together with the "eyes" in the centre of the mill-stones; and instead of the corn being properly ground, the millers designated the process as "chopping," which was a description much too true. When the alterations to remedy these defects were proposed, the makers of the Engines objected. In the first place they would not work under the inspection of other parties; and, secondly, they stated that the proposed alterations would not answer. So confident were they of this, that they refused to work out the alterations even if the plans were placed in their hands without control or inspection. The owners of the Engines were not, however, to be thus intimidated by men carrying pretension too far; and, as "necessity has no law," the stoppage of the Engines was a necessity they could not disregard.

The plan of alteration adopted and carried out was as follows:—The exhaust-pipe of the High-pressure Engine was disconnected from the Low-pressure Engine, and conducted to the Low-pressure Engine condenser; the valve of the High-pressure Engine cylinder was made to cut off the steam when the piston had travelled one-fourth the length of the stroke; thus allowing the steam to expand in the high-pressure cylinder. On the return stroke, the exhaust steam was condensed in a small cistern, which cistern communicated with the condenser of the Low-pressure Engine. The air-pump of the Low-pressure

Engine carried off the water of both Engines from the one condenser.* In other words, the High-pressure Engine was converted into a Condensing Engine, using steam at a less pressure than before, and expanding it to 7lbs below the atmosphere in what had been the high-pressure cylinder; thus obtaining from the steam 32lbs out of 40lbs, or a loss only of 8 in 40—and the Engines increased in power to a great extent. Previous to the alteration, the loss was 27 in 43. After the alteration, both Engines were worked direct from the boilers; and the valves were set so as to cut off the steam in accordance with the pressure. This course allowed it to expand in the cylinders, making the most of it by taking in the steam at the highest available pressure, and parting with it at the lowest available pressure under the circumstances.

Steam worked expansively in one cylinder, where the Engine is sufficiently strong for expansive action, will be as economical as any other contrivance. The gearing of the two Engines last described was connected; and as the steam in the boilers was of equal pressure, one throttle-valve governed the two Engines.

This is an example of a High-pressure Engine being converted into a Condensing Engine; a Compound Engine being changed into two Condensing Engines, with one air-pump. On the areas of the two pistons, after the alteration, the steam acted with greater force—as a great portion of the resistance was removed by forming a partial vacuum in the two cylinders. The

* See page 240, where there is an extract from Mr. McNaught's specification, dated 1859. The Engine of Messrs. Sugden was altered years before the "claim" of this specification was made; also one at Messrs. Fielding and Jackson's, of Blackburn, as well as two at Glossop, and several others.

result was a great augmentation of power. There was no "back-lash," but steady turning; and the process of grinding was more perfect, with considerably less wear and tear. Before the alterations the Engines were not able to drive the whole of the machinery. Since the change they easily do this, and have had more added to them. The extra quantity of work now performed, with the regularity of speed, and the increased power, are sufficient proof of the advantages of the changes made. These facts prove also how people are sometimes misled by those who ought to know more of the business they follow. Had the proprietors in this case given in to the dogmatism of those in whose hands they had originally placed themselves, their Engines would still have been in the defective state formerly described, to their great annoyance and loss. As it is, they are reaping the benefit of the alterations which the makers of these defective Engines would not countenance.

Diagrams Nos. 78 and 79 were taken from a pair of Beam Engines working together, one high and one low-pressure, belonging to Messrs. JAMES BAYLEY AND SONS, Albion Mills, Staley Bridge. The steam was 90lbs to the square inch, generated in one of "HOPKINSON'S Patent Transverse Safety Boilers." The high-pressure cylinder is 20 inches diameter, with a seven feet stroke, working 20 strokes per minute. The Low-pressure Condensing Engine cylinder is 38 inches in diameter, with a seven feet stroke, and also working 20 strokes per minute. The steam from the high-pressure cylinder exhausts into the low-pressure condensing cylinder, working stroke for stroke. These Engines are giving out 225 horse power, with 22 tons of common "slack," or small coal per week—the

of the mill, &c., included. Before the com- of these Engines was effected, with high ıerated in the new boiler on the safety

DIAGRAM No. 78.

n the Top of the High-pressure Cylinder of a Compound Engine.

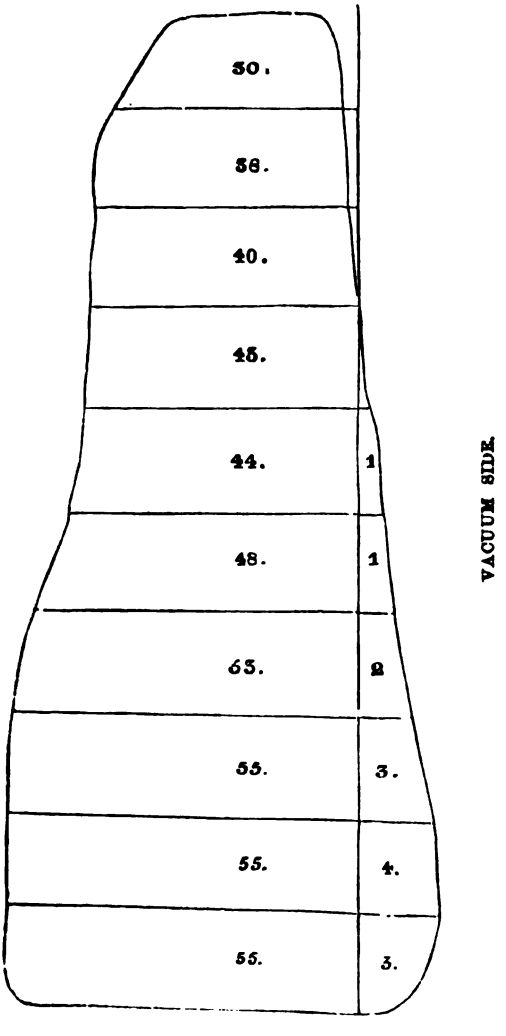
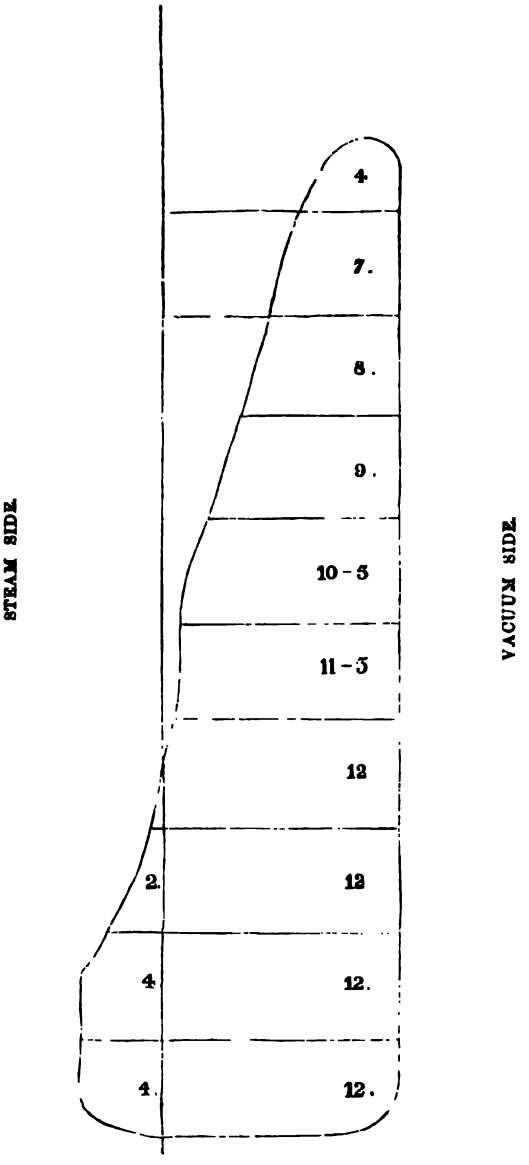


Diagram No. 79.

Taken from the Top of the Low-pressure Cylinder of a Compound Engine.



principle, the greatest item in the working of the establishment was the cost of coal; but since the change the expense of oil to lubricate the machinery is greater than the cost of fuel used to propel that machinery; and although this boiler works at a pressure of 90lbs to the square inch, there is much less wear and tear than at most other places where the pressure of the steam is much less. And as the proprietors do not apprehend a boiler explosion, because of the secure principle of boiler-construction adopted,—a construction calculated to resist a pressure of 700lbs to the square inch,—it is not necessary to employ any one to examine and "report" upon their boilers and Engines. These boilers are provided with two of "HOPKINSON's Patent Compound Safety Valves." Should the water become insufficient, the valves let out the pressure and render further working impossible, until water be supplied in sufficient quantity. The valves cannot be tampered with, or the pressure increased, while the boilers are working. As regards the consumption of smoke at this place, very little is made—the furnaces having sufficient area, so that the fuel does not require to be constantly disturbed. All these advantages have been secured by a comparatively small outlay. Compare the results obtained in this case with the common run of cases, and the advantages are most marked—indeed extraordinary; while the simplicity of the plans adopted ensures durability and permanence to the improvements effected. High-pressure steam can be used with greater safety than most low-pressures with the present large flat-ended boilers. This can be effected simply by having boilers of the simple form of construction—of the cylindrical form, with "egg ends."

On examining the high-pressure diagram (No. 78), it will be perceived that there is a partial vacuum on the exhaust side equal to 4lbs for part of the stroke—and a back-pressure for the other part. This shews that the steam has not much space betwixt the two cylinders to expand in—a point of great importance. Whatever loss is sustained between the two pistons cannot be recovered again; because, necessarily, so much less force will be brought upon the large area according to the amount the steam has expanded before exerting its power in the second cylinder. On examining the low-pressure diagram (No. 79), it will be seen that there are 4lbs above atmosphere at the commencement of the stroke, and 5lbs below atmosphere at the termination of the stroke. This accounts for the partial vacuum at one portion and the back-pressure at the other portion of the stroke, as shewn by the high-pressure diagram.

ON THE COMPOUNDING OF NON-CONDENSING ENGINES.

Having previously explained the advantages to be derived from compounding Condensing Engines (see page 218), we will now endeavour to shew that equal, or greater advantages may be derived by compounding Non-condensing Engines, using very high-pressure steam. The manner in which this can be effected is by using two or more cylinders, the same as in the case of High and Low-pressure Engines; excepting that under the plan now proposed, the steam from the Non-condensing Engines will exhaust into the atmosphere; therefore, 15lbs or upwards will be lost,

there being that amount of resistance to overcome. But where the steam is at a very high pressure, say at 300lbs per square inch, the loss of 15 in 300 is less in proportion than in Condensing Engines worked with steam on the piston at 20lbs per square inch above the atmosphere, and expanded in the cylinder to 8lbs below atmosphere; for in the last case the loss would be 7 in 35, or one-fifth of the whole, besides the power required to work the air-pump; while with the very high pressure supposed there would only be a loss of 15 in 300, or one-twentieth. The loss will be in proportion with steam at other pressures. When the system of high-pressures can be fully carried out, they will be found more economical—in fuel, water, space, and outlay—than the present system in its best examples. To accomplish this, all that is necessary is a properly constructed boiler, and superheating the steam with the waste heat. In time, this principle of high-pressure will be applied to Marine Engines as well as to Stationary Engines.

If we consider the practical application of high-pressures in Locomotive Engines, we are forced to contrast the two branches of Railway and Stationary Engineering. Why is it, that the former should have advanced so rapidly, with such manifest advantage, and the latter have comparatively remained as its name indicates—*stationary?* What more is required to bring the latter up to the standard of the former, than a practical application of the same principles? —the principles laid down by WATT, HORNBLOWER, and WOOLFE. It is but just to the memory of these men to state that the principles of the major portion of the improvements since effected in the Steam Engine,—whether Stationary, Marine, or Locomotive,

—were clearly seen and enunciated by them; and that it is mainly in material and workmanship that we exceed them or their day.

The principle of compounding Non-condensing Engines (when we learn how to apply high-pressure steam) can be so easily accomplished, and in so small a space, that a small High-pressure Engine could be fitted in each room in a mill. In that case all that would be necessary would be a small steam-pipe carried to the work, instead of the heavy shafting and gearing now in use. The different rates of speed for the machinery could be varied by the different speeds of the Engines, which would be a great convenience. Under such a system, a break-down or a stoppage would not affect the whole of the rooms, as in the case of our present heavy Engines, with their strong buildings, massive shafting, and ponderous gearing. It only requires time to bring about these changes: for ultimately they will be as practical in the case of the Stationary as in the Locomotive Engine. Each room in a mill would then have its own management, and be wholly independent of any other. Auxiliary Engines, taking little space, and using high-pressure steam, could also be made available for sailing vessels, to propel a movable screw, or some other propeller, that could be set in action when required.

WORKING STEAM IN TWO CYLINDERS: FIRST, A HIGH-PRESSURE CYLINDER: THENCE TO A BOILER: THENCE INTO A LOW-PRESSURE CYLINDER.

For this method of compounding, the steam should be at 90lbs pressure, or more, in the boiler, and be applied so as first to work a single or double High-pressure Engine. In the high-pressure cylinder the steam would be 80lbs to the square inch, let on for five-sixths the length of the stroke. This cylinder, or pair of cylinders combined, should be one-eighth the area of the condensing cylinder. After passing through the High-pressure Engine, the steam should then exhaust into a separate steam boiler, through a valve, opening inwards. Each stroke of the Engine would force the valve open, and admit the steam into the boiler. The valve would close by the pressure in the boiler, on the return of the stroke of the High-pressure Engine. The steam for the Low-pressure Engine would be one uniform pressure at the beginning of each stroke upon the piston of the Low-pressure Engine; and then by working the steam expansively, cutting off in the ordinary way, the steam would be used from the highest pressure in the low-pressure boiler down to the lowest pressure possible in the low-pressure cylinder. This plan would realise all the power contained in the steam, except the loss at the end of the stroke of the Low-pressure Engine; that loss being the quantity of steam to be condensed, which ought not to exceed half an atmosphere, or 7½lbs.

The principle and action of this description of

Engine would be as follow:—the steam from the high-pressure boiler would work a High-pressure Engine with a small cylinder, say $12\frac{3}{4}$ inches diameter, travelling 350 feet per minute. With the pressure upon the piston at 80lbs above atmosphere, cut off at five-sixths the length of the stroke, the power would be 82 horse. This Engine would be connected with the shaft of the Low-pressure Engine. The steam, on leaving the high-pressure cylinder, would exhaust into a low-pressure boiler, which boiler would have to be supplied with water in the usual way, and be set up with a furnace, the same as any ordinary boiler. A slow fire would have to be maintained, to replace the condensation of steam that would take place. Suppose the exhaust steam from the High-pressure Engine to be 15lbs to the square inch above atmosphere, this 15lbs would be a regular back-pressure on the high-pressure piston. Suppose also that the low-pressure boiler was worked at 15lbs pressure per square inch, and 15lbs pressure brought upon the piston of the Low-pressure Engine, cut off at one-fourth the stroke, and the steam allowed to expand the remainder; the diameter of the cylinder being 36 inches, the piston travelling 350 feet per minute, the steam at the end of the stroke would be half an atmosphere, or $7\frac{1}{2}$lbs. There would, therefore, be this quantity to condense at the termination of the stroke. The pressure upon the piston of the Condensing Engine being 15lbs, cut off at one-fourth, the average would be $17\frac{3}{4}$lbs to the square inch. If the cylinder was 36 inches diameter, and the speed of the piston 350 feet per minute, this Engine would give out 190 horse power from the exhaust steam of the High-pressure Engine. The total of the combined

power of the two Engines would be 275 horse. The Engines could be fixed at right angles, which would balance and steady the power, producing even and steady turning—a matter of great importance in most manufactories; or the Engines could be independent, working at any required speed. All this could be accomplished with 3lbs of coal per hour per horse power, if steam of great pressure was used, and if the high-pressure cylinder was sufficiently small: for it should always be borne in mind that in proportion to the lesser area of the small piston, is the amount of back-pressure reduced.

This principle of compounding can be applied to the Marine Engine; and undoubtedly the time will arrive when most of our steam ships will be propelled with Compound Engines, worked by high-pressure steam, with greater safety than at the present time with the large, dangerous, and complicated boilers in use. We see no reason why sailing vessels should not be provided with steam power, to be available for every purpose where power is required—in calms, or in storms. The power of steam might be used to advantage, and particularly for pumping purposes. A Steam Engine does not require rest. To that machine day and night are the same. Such an instrument of power ought, therefore, to be more generally adopted than it is by our mercantile marine.

NON-CONDENSING HIGH-PRESSURE ENGINES EXPANDING THE STEAM IN ONE CYLINDER.

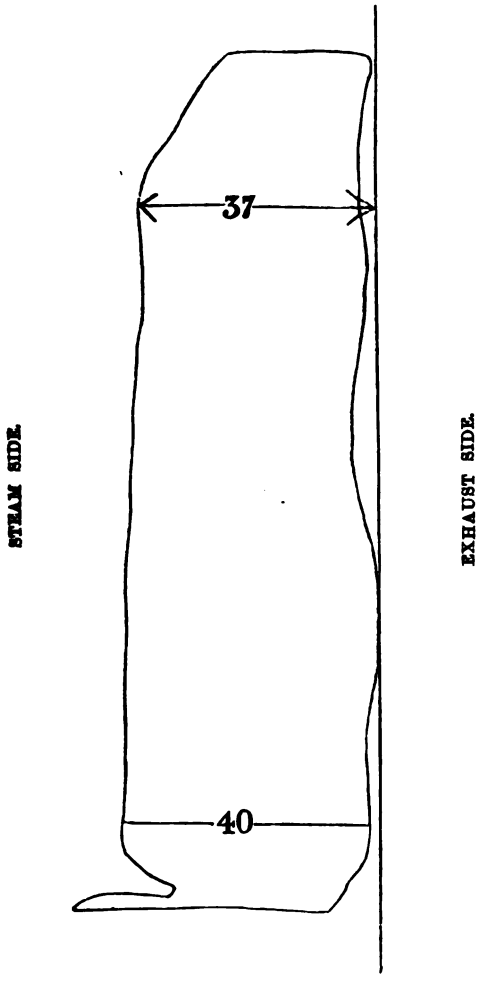
In what has been advanced regarding the expansion of steam in one cylinder, the examples adduced have had reference mainly to Condensing Engines; but as there are a great number of Non-condensing Engines working steam at various pressures, it may not be out of place to notice their construction, and the means whereby, in most cases, their power may be increased.

For example: suppose that steam is admitted upon the piston of an High-pressure Engine for the whole length of the stroke—the average will be the full pressure. But, suppose again, that the same Engine is provided with a cylinder of increased diameter, and the steam cut off so that it can expand the remainder of the stroke: in this last case, the saving of fuel would be in the ratio of the amount of expansion. For economy, steam should be brought upon the piston at its highest pressure, and should be cut off at such part of the stroke that it can expand to the lowest practical point before exhausting into the atmosphere; that is, admit it to the piston at the commencement of the stroke at its highest pressure, and part with it at the lowest available pressure at the termination of the stroke. When this is done, all the available power will have been obtained from the steam employed. But where the steam is allowed to leave the cylinder at the same, or nearly the same, pressure as it entered, great loss is sustained. For example: diagram No. 80 represents the full pressure of the steam on the piston the whole length of the cylinder; and diagram No. 81 is an example of an

character. It was taken from a High
Engine belonging to Mr. J. W. MOTT, Le
Road, Clapton, London, where fuel is exces

DIAGRAM No. 80.

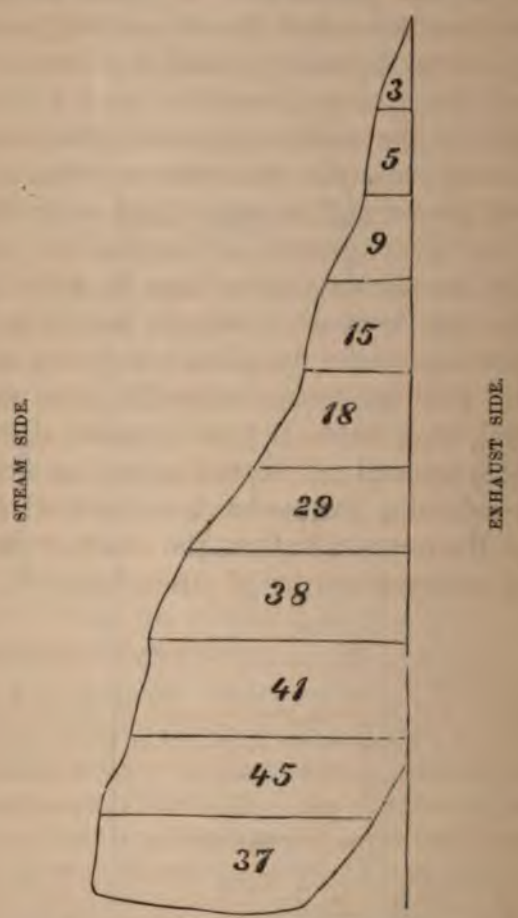
Taken from the Top of a High-pressure Cylinder.



sively dear. It is evident that the first Engine is consuming much more fuel than the latter for the work done. In the Engine from which diagram

DIAGRAM No. 81.

Taken from the Top of a High-pressure Cylinder.



No. 81 was taken, the steam was brought upon the piston at the commencement of the stroke, cut off at

one-third, and expanded the remainder, down to about 5lbs above atmosphere, shewing that the steam was well used up, and that the most available power had been obtained from steam at that pressure. The cylinder of this Engine is 14 inches in diameter, 2 feet stroke, 70 strokes per minute—or 280 feet per minute. It was erected as a 14 horse Engine—but by proper nominal calculation it is a little over. The average pressure upon the piston is 24lbs per square inch, and the power exerted is equal to 30 horse. The nature of the machinery this Engine has to drive is of a very variable character—sometimes taking very great power, and at other times very little. To remedy the uneven turning of Engines so worked, it is usually considered that a large fly-wheel is necessary. In this instance, however, that idea has not been acted upon—the fly-wheel being only six feet in diameter. Still the Engine runs with great regularity.

The following letter is from a practical Engineer; and as this principle of expanding in one cylinder of a Non-condensing Engine has been carried out by the writer of the communication, the result of the alteration will be found worthy of attention :—

"*Duckinfield, April 5th*, 1857.

"Mr. J. Hopkinson.

"Sir,—I wish to draw your attention to the particulars of an experiment with a High-pressure Engine, which I have been conducting at the Central Works, Sheffield, belonging to Mr. Shortcliffe. The Engine had a nine-inch cylinder. The steam was admitted during the whole length of the stroke, without expanding. The boiler evaporated 900 gallons of water in five hours, with a weekly consumption of twelve tons of coal. The pressure was 72lbs per square inch in the boiler, and yet they could not maintain the speed of the Engine when all the work was on.

"The alteration which was made was simply replacing the nine-inch

cylinder with one of 13 inches diameter, and arranging the valves so as to cut off the steam before the piston had travelled half the length, allowing the steam to expand the remainder of the stroke.

"Sir, if I must state what was the general impression amongst the Engineers of Sheffield, it was to this effect: that the new cylinder would drive the work, provided there was an additional boiler to supply it with steam. Only imagine their surprise, when they found that the Engine was driving the whole of the work at the proper speed, and the boiler only evaporating 415 gallons of water in five hours, at 55lbs pressure—less by one-half than what was required before; and this, too, with half the firing. Instead of requiring another boiler, we had half the present boiler to spare for other purposes.

"Since the alteration, additional work has been added to the Engine; still the weekly consumption of coal is only seven tons.

"This result, good as it is, is nothing more than you would expect from allowing the steam to expand, over that of no expansion at all.

"In travelling the country, I find that a great number of owners of Engines have yet to derive the advantages which others are deriving by allowing the steam to expand before leaving the cylinder. The reason of this is, that the means of carrying out expansion and early exhaust are but little understood by those who ought to have a practical knowledge on the subject. No doubt one great cause is a want of a more general knowledge of the *Indicator*, and its frequent application, in order to obtain that information which it is enabled to convey respecting the interior of the Engine.

"The diagrams from the Condensing Engine I enclose will shew you the former and present state of the Engine alluded to. By the first figure it is apparent that the valves were in such a state that 63 indicated horse power was the very utmost the Engine could drive at the proper speed. It is now working 146 horse power, with a less consumption of steam than before.

"I feel convinced that parties who wish to work their Engines with economy, can accomplish that purpose by applying the *Indicator*, and studying the cause of its peculiar delineations upon the paper. By this means they may obtain a sound knowledge of the working of any Engine, and ascertain where improvement is practicable.

"I confess I am greatly indebted to that instrument, and remain,

"Yours truly,

"ENOCH GLEDHILL."

In the case referred to, great advantages have been

derived from the alteration detailed. Similar results would have been obtained by using the small cylinder, with an increased pressure of steam, worked expansively.

It is from the high-pressure expansive principle alone that we are enabled to travel at great speed on railways; and it cannot be controverted that High-pressure Stationary Engines are, on the average,—for the effects produced,—consuming more than double the quantity of fuel to that consumed by Locomotives. So little do makers of High-pressure Engines appear to understand the principle of using steam expansively, that it is rare to meet with a High-pressure Engine with its valves set to cut off the steam until very near the termination of the stroke. The exhaust has almost invariably too little "lead," and the thoroughfares are too small; thereby entailing a back-pressure upon the piston—or, in other words, a loss of power. The hints here given will indicate to the practical Engineer how the remedy is to be applied; and if this be effected judiciously, similar beneficial results to those detailed above will follow.

DIRECT-ACTING HORIZONTAL CONDENSING STEAM ENGINES.

THE accompanying plate (No. 82), represents a 20 nominal horse power Direct-acting Horizontal Condensing Steam Engine. It contrasts greatly with the beam construction hitherto generally applied to Condensing Engines. The great change now taking place with regard to the form, construction, and working of Steam Engines, is a subject on which we might dwell at great length; but we here content ourselves by giving this plate as an example of one of the departures from the ordinary construction. The economy in construction and room, besides the advantage of strength combined with simplicity—there being fewer parts for wear and tear—should be inducements for its adoption. Should a *break-down* occur, the damage will be much less compared to such an occurrence with a Beam Engine, with its massive beam, connecting-rod, pillars, etc.

On reference to the plate, it will be seen that the condenser and air-pump are placed at the back end of the cylinder, in a place easy of access. The air-pump is worked by links from the back piston-rod attached to a bell crank; the cylinder valves are worked by the ordinary eccentric; and the Engine is governed in the usual way. The whole of the working parts are bound together on one frame, and are therefore not liable to be separated or strained by the foundation or building giving way.

By some parties it has been urged that the lower portion of the cylinder of a Horizontal Engine wears more than the other parts. This objection is not verified in practical working. With the cylinder placed horizontally it is found to work equally as well as a vertical cylinder and piston—and in the same way, too, wearing the cylinder a little wider in the centre. Of course the horizontal cylinder requires, like all other cylinders, to be made of a good quality of metal; and then, when worked with a metallic piston, there is little chance of any uneven wear.

The objection before named was first started by theorists and authors on the Steam Engine, and was supported by those whose interest in Engine building it was to continue to construct in the old methods—it not being convenient to make new patterns and alter their routine of business.

Plate No. 83, represents the same Engine, except that the air-pump is here double-acting, and is placed horizontal, like the cylinder, and is worked from the back piston-rod: thus doing away with the slides, the L leg, and the connecting-rod.

Horizontal Direct-acting Engines are now becoming general, and former prejudices against them are fast dying away.

In May, 1861, at a meeting of a Cotton Manufacturing Company, in Rochdale, a discussion arose as to the merits and demerits of the Direct-acting Horizontal Engine as compared with the Beam Engine. A report of that meeting appeared in the *Rochdale Spectator*, on the 18th of that month, part of which we give because of the truths spoken by a "Mr. M——," and the extraordinary letter of Messrs. J. Petrie and Co., setting forth some new principles,

and urging objections to Direct-acting Engines never before heard of, except amongst obstructives, who are always ready to denounce improvements. At the meeting in question

"Mr. M—— stated that the Board of Directors had had the opinions of many disinterested persons, who told them if they studied the interests of the company, they would have Horizontal and not Beam Engines. The Directors had at different times gone at their own expense to see the working of different sorts of Engines; and after a careful investigation they had determined upon what they thought best for the interests of the company. They had had Mr. M'NAUGHT at one of their meetings, and he, like the Messrs. PETRIE, of Rochdale, and MUSGRAVE, of Bolton, advocated the kind he made; and whichever maker they went to, they were sure to be told that the sort they made was the best; but the Directers had not been guided by what the makers said. They had the testimony of parties retired from business, and who could therefore have no interest in recommending any but that which they believed to be the best. These to a man recommended Horizontal Engines. He then offered any man present, if he was in favour of Beam Engines, five pounds, if he did not say, after he had seen both working, that Horizontal were superior to Beam Engines. He would give the five pounds as freely as ever he gave a shilling to his wife; and he concluded by comparing Beam Engines to the ancient bobbin-wheel."

This "Mr. M——" (one of the Directors), spoke out plainly; and there is too much of truth in his remarks.

At the same meeting the following letter from Messrs. PETRIE AND Co. was read:—

"*Rochdale, March 25th*, 1861.

"Mr. JAMES BUCKLEY:

"SIR,—In reply to your inquiry as to the relative merits of Beam Engines and Direct-acting Upright Engines for spinning purposes, we have no hesitation whatever in stating that the Beam Engine is decidedly the best, as all experience has proved over and over again. In the first place, the Direct-acting is almost always a short stroked Engine, seldom more than 3ft. 6in. or 4ft. stroke. It cannot, conveniently, be otherwise, as a long stroke would necessitate the fly-wheel shaft being a great height

up, or the cylinder, &c., being down in a deep pit, both very objectionable, the nearer to the bottom floor of a mill the main power can be taken off, the firmer and better. Second : the short stroke compels high speed, and consequently great wear and tear of the working parts, the air-pumps and connections, especially, get continually out of order. If you only consider that the diameter of the neck of the fly-wheel shaft, say of any 40 horse Beam Engine, is 11¼in., running 30 revolutions per minute, and then ascertain the diameter of the fly-shaft neck of any 40 horse Direct-acting Engine, and its number of revolutions, your own common sense will tell you which is most likely to work for a long period without requiring renewal; and the same remark applies to all parts of the Engine. Third : in short-stroked Engines you cannot cut off the steam earlier than half stroke with advantage; so that the steam can only be expanded to twice its volume, while in the long-stroke it is expanded to five times its volume, which effects a great saving in coal. Fourth : in all the Direct-acting Condensing Engines we have examined we find that owing to the cylinder being put at a lower level than the boilers, the Engine is very subject to priming—so much so, that to prevent continual break-downs it is necessary to apply water safety-valves to the ends of the cylinder, which, when the dirty water from the boilers is forced through them, we need not tell you makes a mess of the Engine.

"The above are a few of the most prominent objections to the Upright Direct-acting Engines, and the Horizontal Direct-acting Engines are, if anything, still more objectionable. We are aware that, owing to there being little more than half the weight of metal in the Direct-acting Engine, it can be made for much less money; and where the first cost is the principal object, they are sometimes put down as a stepping-stone to the other; for instance, a 40 horse Direct-acting Engine for working with steam at 40lbs to 50lbs in the boiler, if of the best construction, with centres or pivots of motions made of mild steel, or case-hardened iron, would cost £700, while a 40 horse Beam Engine would cost £950; but the saving of coal alone by the latter would pay good interest on the whole cost of the Engine, and for durability there is no comparison.

"The above, as we have said before, are a few of the more *prominent* objections to the Direct-acting Engine, and will be quite sufficient for any one who has any knowledge of, or has had any experience with, Steam Engines generally.

"We are, yours respectfully,

"JOHN PETRIE & CO."

The extraordinary statements of this letter are

contrary to "common sense." We are at a loss to know how Messrs. PETRIE AND Co. have discovered that Direct-acting Engines have "almost always a short stroke." We apprehend that Direct-action Engines, like all others, are made long or short-stroked, according to circumstances—because there is nothing to prevent them from being so made. This portion of the letter we assume to be a piece of pure imagination. Then we are told :—"the nearer to the bottom of the floor of a mill the main power can be taken off, the firmer, and the better." This self-evident truth no one will dispute; and the Direct-acting Horizontal Engine fulfils this desired object to the letter. This is a feature peculiar to the Horizontal Engine that "common sense" has long since discovered; and we wonder the writers of the letter did not discover that no other Engine yet known of lies *nearer* to the floor of a mill than the Horizontal Engine; and that the foundation for such an Engine does not require to be one-third the weight and bulk of the foundation of a Beam Engine. Neither does the former require the same strength of an Engine-house wall as the latter—because there are no parts of the Engine fixed to the wall as there are in large Beam Engines. The latter are entirely held in their place by heavy foundations and walls; and these too often give way, from the continual strain upon them. In the Mechanical Section of the British Association, at the meeting held in Manchester in 1861, a paper was read by Mr. JOHNSON on the "Advantages of Direct-acting Engines over others"; and Mr. SCOTT RUSSELL very justly observed—that formerly Steam Engines were partly built of stone; but since the direct-acting principle had become better understood,

there was no necessity for much stone work. He, along with many eminent Engineers who took part in the discussion, strongly approved of the Direct-acting Engine in preference to the Beam Engine.

Then we are told that "a short stroke compels high speed." Whatever the length of the stroke, the speed of the piston is the same, though the revolutions may be more or less. The wear and tear of the "fly-wheel neck" will be the same in all cases, whether the Engine be a Beam, a Horizontal, a Vertical, or any other description. When the speed is quicker, the "fly-wheel neck" does not require to be so large in diameter; therefore, the travelling of the surface of the neck is no greater than with a long-stroked Beam Engine.

Then we have the assertion—"In short-stroked Engines you cannot cut off the steam earlier than half stroke with advantage." As Messrs. PETRIE AND Co. have appealed to "common sense," we do not think it requires much of that quality to discover the fallacy of the doctrine here laid down respecting the cutting off steam in a short-stroked Engine. What difference can it make to the steam, whether the cut-off be on a short or long stroke? The steam is cut off at a certain angle of the crank, when the piston has to travel the same distance in proportion to the length of the stroke, whether the latter be long or short. If the steam be cut off when the crank is at the same angle in both cases, the expansion will be the same in both instances. Messrs. PETRIE AND Co. are wrong in their statement that steam can be expanded better in a long-stroked Engine than in a short-stroked one. Such a statement to be sent forth to the world from an eminent Engineering establishment,

proves too clearly what we have stated in the former part of this work—that expansion is not thoroughly understood by many Engine builders. This will account for the folly of compounding Engines under certain circumstances, where all sorts of dimensions of cylinders are used for steam at the same pressure.

Then Messrs. PETRIE AND CO. say:—"In all the Direct-acting Condensing Engines we have examined, we find that, owing to the cylinders being put at a lower level than the boilers, the Engine is very subject to priming."

Reasoning out this statement, it must follow that in the Locomotive and other Engines, where the cylinders are placed *below* the boilers, the Engines must prime, and be subject to break-downs. What difference it can make to the water in the boiler, whether the steam has to rise or fall when it has left the boiler, we have yet to learn, and should think Messrs. PETRIE AND CO. have to do the same. They may draw upon imagination; but such fancies ought not to be put forth as though they were facts. We remember a case of an Engine often priming at starting. We were called in to devise means to prevent this. The proprietor and the Engine-man both stated that the Engine was placed too low, or that the boiler was placed too high; and that this caused the priming. Not believing in a mere fancy, we wished to have the matter tested before the boiler was removed, as was proposed. The Engine was therefore stopped, and started again, and behold, priming did take place! To all appearance there could be no doubt but that the boiler was in the wrong place. Had this case been under "inspection," probably there would have been a long report, shewing the necessity for the boiler being removed. Instead

of this, however, it was proved to the proprietor and his Engine-man that the boiler was not the cause of the priming, as they had been informed; but that the man did not properly understand how to stop and start his Engine. When he stopped the Engine, he did not close the injection-valve; and as there was a partial vacuum in the cylinder, the pressure of the atmosphere upon the surface of the water in the air-pump cistern forced water into the cylinder while the Engine was standing: consequently, at starting the Engine, the cylinder was charged with water. This was called priming, but it was no such thing. It was not water from the boiler, but water from the cistern. The cause was pointed out, the matter was afterwards attended to, and "priming" ceased. To make sure that the water would be kept out of the cylinder, in case the valve should leak or there be a bad joint, we had a small pipe and tap inserted in the steam pipe leading to the condenser, so that when the Engine was stopped this tap could be opened, and air admitted to destroy the vacuum. This effectually put an end to the "priming."

Many Engines have been broken down in consequence of the injection-valve having been left open, or some joint leaking. Water has thus got into the cylinder while the Engine was standing: and, at starting, the consequence has been more than "a mess"—a breaking of the beam or other parts.

There are other portions of the letter of Messrs. Petrie and Co. that are equally mischievous in their tendency, because they propound doctrines incompatible with "common sense"; but we pass them over, convinced that the samples we have selected and commented on will be regarded as a fair representation of the bulk.

NOVELTIES IN THE CONSTRUCTION OF A DIRECT-ACTING HORIZONTAL CONDENSING ENGINE.

Plate 84 is a representation of a 57 nominal horse power Horizontal Direct-acting Engine, erected at the Britannia Mills, Huddersfield, by the author. As there are some deviations in construction from the ordinary Horizontal Engine, we shall point them out as briefly as possible.

The cylinder, A, is 40 inches diameter, inside measure. The piston has a five-feet stroke, working 40 strokes per minute—or travelling 400 feet per minute. The two ends of the cylinder are cast with hollows, partitioned so as to make two cavities in each end. The cavity next the inside of the cylinder is supplied with steam direct from the boiler, to keep up the temperature of the cylinder. The cavity next the outside of each end is filled with a non-conducting material, to prevent radiation of heat, and the ordinary action of cold air. The piston-rod is of steel, five inches in diameter.

The crank, B, is formed of a large plate, instead of the ordinary form of crank. The crank-pin, C, is of steel, 6½ inches diameter. This is fixed to the plate in the usual way. The object of having a plate instead of the ordinary form of crank will be apparent —it is to have the means of balancing the connecting-rod and crank, and the construction is also much stronger than the ordinary crank. On the back of the plate, and opposite the part where the crank-pin is fixed, a portion of the rim is made heavier than the rest, so as to balance the weight of the connecting-rod D. E is the fly-spur wheel, 15 feet 6 inches in

diameter, and 12 inches broad on the tooth. The teeth have a flange cast on each side, half the height of the teeth, to connect the latter together, thereby strengthening them. The pinion-wheel is seven feet in diameter, and is flanged in the same way. The fly-wheel shaft is made of wrought iron. It is 16 inches diameter in the centre, 11 inches in the necks, which are 22 inches long. There is an eccentric on this shaft, shewn at F. The eccentric has a throw of nine inches. It is six inches broad on the face. This eccentric works two air-pumps by a ⊥ beam—one pump at each end. The end of the air-pump beam is shewn behind the cylinder, at the place marked G. One of the air-pump tops is shewn at H. The air-pump rods are eight inches in diameter. The connecting rods from the ends of the ⊥ beam are affixed to the bottom of the rods inside the trunks. These trunks work in stuffing boxes and glands, which form guides, and keep the pump-rods parallel. The diameter of the pumps is larger than usual—but the stroke is also much shorter. While one pump is descending, the other pump is ascending. They thus balance each other, and the water from the condenser is regularly pumped out. On the axis of the ⊥ beam there is an arm and connecting-rod, which works the rock shaft I, and the arm J, which, by a pair of links, communicate motion to the valve-rod K, by a cross head. There are two separate valve boxes, L L,—one at each end of the cylinder. Each box contains an ordinary flat, or two-port slide-valve, worked by the rod K, through a stuffing box. The steam enters these valve boxes by the steam ways M M. These steam ways are supplied with steam from the expansion-valve box N. The bottom of this last-named valve box is

provided with two openings, opposite each other—each communicating with its own steam way. In that expansion-valve box there is also a flat plate, with one opening only, and the plate covers the openings in the valve box bottom. It is made to revolve by means of the bevel wheels, o o, driven by the governor shaft P. As the plate revolves round, the opening in the plate uncovers the two steam ways in turn—this valve box being constantly supplied with steam from the boiler, through the throttle-valve Q. When the opening in the revolving plate is opposite one of the steam ways leading to one end of the cylinder, the steam passes into the slide-valve box. When the opening in the expansion-valve has passed over the opening in the bottom of its box, and thus closed the communication to that particular slide-valve box, the steam that had passed while the opening in the revolving plate was uncovered, has now passed to the piston by means of the slide-valve in the valve box L. When the opening in the expansion-valve plate closed, the steam from the boiler was cut off, and no more steam can enter the slide-valve box until the piston has made one full stroke. Thus the steam in the valve box L is made to expand down with the steam in the cylinder, for one half of the stroke. For the other half of the stroke, there is no steam in the slide-valve box at all—consequently, there is no pressure upon the slide-valve, until the revolving-valve plate of the expansion-valve uncovers the opening again, to admit another supply of steam to the slide-valve box. This will again be closed when the piston has traversed 15 inches out of the 60. By these means the steam is cut off at that distance, or at any point arranged for, by having

the openings in the revolving-valve plate larger or smaller, or giving those openings a greater or less amount of lead, which will cut off the steam earlier or later, in proportion to the lead. The other slide-valve, placed at, and communicating with, the other end of the cylinder, is worked precisely in the same manner: the one opening in the revolving expansion-valve plate uncovering each steam way in its turn.

It is well known that with valves having much "lap," or where there are expansion-valves to cut off the steam early, there is difficulty in starting an Engine. In this construction, this difficulty is provided for. There is a handle-wheel at R, by turning which the expansion-valve plate is *raised* from its seat, continuing to revolve at the same time. Thus, at starting the Engine, when the revolving-valve plate is raised, the steam passes to each slide-valve box in the usual way, being on at full pressure for the full length of the stroke. The slide-valves having little or no "lap," the Engine can be started without difficulty. When the Engine is fairly on its way, the handle-wheel is turned the contrary way, and the expansion-valve plate thereby brought back upon its seat. The process of cutting off the steam then commences.

It is so arranged that the revolving-valve plate does not rub upon the face of the bottom of the valve box. It all-but touches, and this is sufficiently tight for all practical purposes. This prevents a great amount of friction, and consequent wear and tear. At any time the expansion-valve plate can be raised, either partially or wholly, while the Engine is working. The steam can thus be worked less expansively when more work is required.

from 400 to 500 indicated horse power. The work the Engine will have to perform will be, turning one large woollen mill and one large cotton mill, with other attendant and casual machinery.

The steam to supply the Engine, and for the other purposes of steaming, dyeing, and drying, is obtained from five three-feet diameter boilers, 32 feet long. These boilers are made with a tongue projecting from the bottom; and these form fire boxes for the furnaces. The flame and heat pass between the tongues, and under the boilers, into a side flue, where there is a two-feet diameter vessel, 36 feet long, exposed to the heated gases, after these leave the boilers. The steam passes through this vessel, or tube, on its way to the Engine, and is thus superheated in a small degree. The smoke and gases then discharge into a chimney, six feet square at the bottom, *increasing in width* for about half the height of the chimney to eight feet three inches square. This width is then continued to the top—the whole length of the chimney being 47 yards.

This chimney is used for other purposes besides those of the furnaces. For instance: the wool for the woollen mill, after it has been washed in the process of manufacturing, is dried by means of the chimney draught—a mode of drying much superior to, and quicker than, any of the old methods.

The author is attempting still further improvements in the construction of the Horizontal Engine. These are about to be applied to an Engine,—now in course of construction, under his superintendence,—of 35 nominal horse power, and, in general build and form, similar to the "JAMES WATT" at the Britannia Mills.

In this new Engine, instead of the slide-valves being

placed on the upper side of the horizontal cylinder, they will be placed in an inclined position near the under side of the cylinder. The thoroughfares will be level with the lowest part of the cylinder—so that the condensed steam in the cylinder will pass away with the exhaust steam. At present, with the slide-valves on the upper side of the cylinder, there is always a little water, arising from condensation, left in the cylinder. This at times is evaporated by the heat of the cylinder, and then it interferes with the vacuum. With the slide-valves in the position intended, there will be no necessity for water safety-valves—because in that position the slide-valves will be lifted from their faces, or seats, whenever there is any extra pressure in the cylinder from the presence of water, —as may sometimes happen at starting the Engine, from condensation while it has been standing, or from leakage. This arrangement of the slide-valves will permit the escape of such water, without endangering the Engine.

The slide-valves of the new Engine will also be of novel construction. They will be in every respect equal in simplicity to the two-port slide-valve, but different in the mode of working. The *traverse* of the improved valve will be but one-half the length of the ordinary slide-valve. The steam will be admitted on to the piston much easier than by the present form of construction, and it will be kept on the piston longer, as the exhaust will not require the amount of lead now necessary. In the improved valve, the exhaust will open much quicker than by the present mode; therefore, as before stated, the steam will have time to force the piston further before it is necessary to find means for its escape, and thus prepare for the return stroke.

Instead of the improved slide-valves being moved by the ordinary means now in use, they will be worked *direct* from a leg of the ⊥ beam of the double air-pump—that leg being worked by an eccentric. Under this new arrangement the valves can be regulated with a facility and nicety equal in every respect to the present mode, while one distinct motion will be thus dispensed with.

The stroke of the air-pumps will be short, but the pumps will be much larger in diameter than ordinary. The speed of the piston will be 400 feet per minute: the length of stroke being four feet four inches, and the piston making 45 strokes per minute. In the whole construction great care will be taken to balance all the parts, so as to secure regularity and evenness of motion. The fly-spur wheel will be 13 feet in diameter.

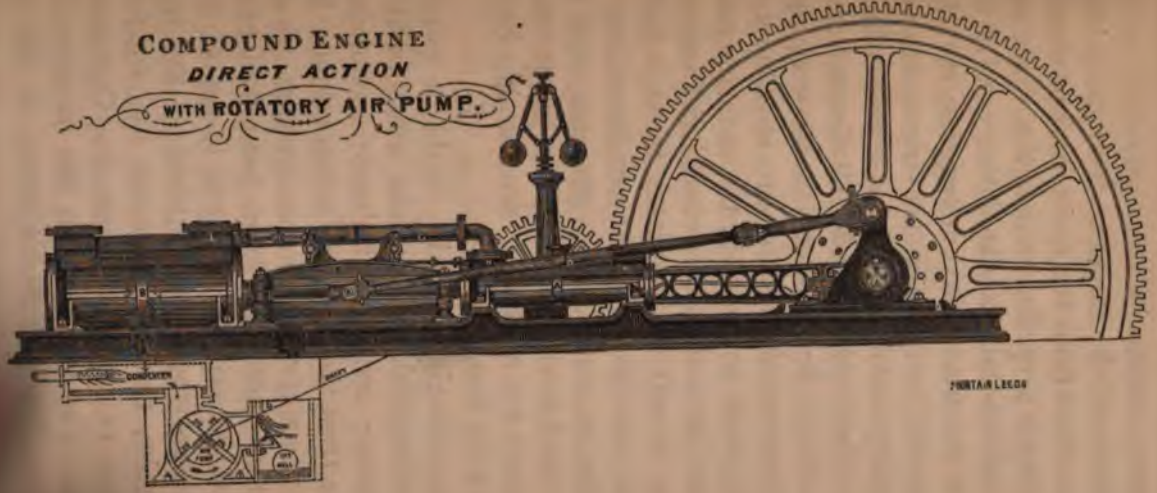
DIRECT-ACTING
HORIZONTAL COMPOUND STEAM ENGINE.

In what has been already advanced on Compound Engines, the various methods described have had reference to facts and circumstances which have come under practical observation. Those facts prove that there cannot be a doubt as to the economy of using steam expansively—working it from the highest pressure in the boiler to the lowest possible pressure in the condensing cylinder—thus obtaining from the steam all the power it contains, by receiving it at the greatest pressure, and parting with it at the lowest. This could be best accomplished, however, with an Engine so constructed that its working parts will be

in proportion to each other, and in accordance with the pressure of the steam.

Having stated the advantages to be derived from using steam expansively, we now proceed to explain the best form of Engine calculated for that purpose, on the compound principle.

In the accompanying engraving of a Single Compound Engine, A is the high-pressure cylinder, of one-eighth the area of the condensing cylinder B. Both cylinders are mounted on one frame, and are connected by one piston-rod, bearing a piston at each end. Between the cylinders are a cross head and guides, which are fixed to the piston-rod of both cylinders, and move backward and forward in slides for that purpose, fixed also to the frame of the Engine. The cross head is attached to the forked connecting-rod D. This connecting-rod strides the small high-pressure cylinder A, except that portion connected to the crank. The shaft and crank are mounted on pedestals, fitted to the frame. The fly and spur-wheel is on the crank shaft. The machinery would be driven by the pinion-wheel, which may be fixed to any other part of the rim of the fly-spur wheel as situation requires. The eccentric is fixed to the shaft in the usual manner—which eccentric works the valve of the high and low-pressure cylinders. The two cylinders are connected by a pipe. The steam, after operating in the small high-pressure cylinder, is conducted through the pipes and valves to the low-pressure cylinder, where it expands. After performing its operation in the large cylinder, it escapes into the condenser below the frame, where a jet of cold water meets the exhaust steam, thereby condensing it, and forming a partial vacuum in the ordinary manner.


COMPOUND ENGINE
DIRECT ACTION
WITH ROTATORY AIR PUMP.

The hot water from the condenser flows into a rotatory air-pump, shewn in the engraving, underneath the framework of the Engine. The pump is propelled by a shaft direct from the main shaft of the Engine. As the pump is propelled round, the vanes of the pump force out the water at the delivery-valve into the hot well in the usual way; excepting that in this case there would be a continuous stream—the pump being continually revolving. Or a double-acting air-pump can be substituted. Under all circumstances the air-pump should be balanced in its working, so as to equalise the strain, and secure steadiness of turning. The Engine is governed in the ordinary manner.

In the Horizontal Direct-acting Compound Steam Engine, as will be perceived, there is but one shaft, one spur and fly-wheel, one condenser, one air-pump, —double or single,—one governor, and two single cranks fixed at right angles; one frame being all that is required for a *pair* of Direct-acting Engines, complete within themselves.

Such an Engine, or pair, would be suitable for any purpose required. The strain would be all within its own frame; and thus be more economical in wear and tear than the ordinary construction. Should any of the parts give way, the damage would be less than where there is a large beam and pillars. The decreased quantity of material is also of importance. Less power would be required at the reversing of each stroke, there being much less weight to move backward or forward than in Compound Beam Engines. The reduction in the number of working parts, and the general lightness of the Compound Engine, with its increased power, are good features, requiring less attention in management—a consideration of importance.

This description of a new Horizontal Compound Engine is here introduced in answer to repeated enquiries as to what kind of Engine it is preferable to use on the compound principle. In laying that plan before the public, the author would state that he has endeavoured to keep in view six essentials for a good Engine, viz: balancing the parts, economy in construction, economy in room, economy in working, economy in wear and tear; and last, but not least, a construction which will allow every part of the Engine, and particularly the valves, to be examined with facility. By the practical Engineer these points will be recognised as of importance, because they enable him to keep his Engine in proper repair. Another advantage is, that when repairs are necessary, the parts of the new Engine are much less in bulk than those of the Beam Engine of the same denominational power.

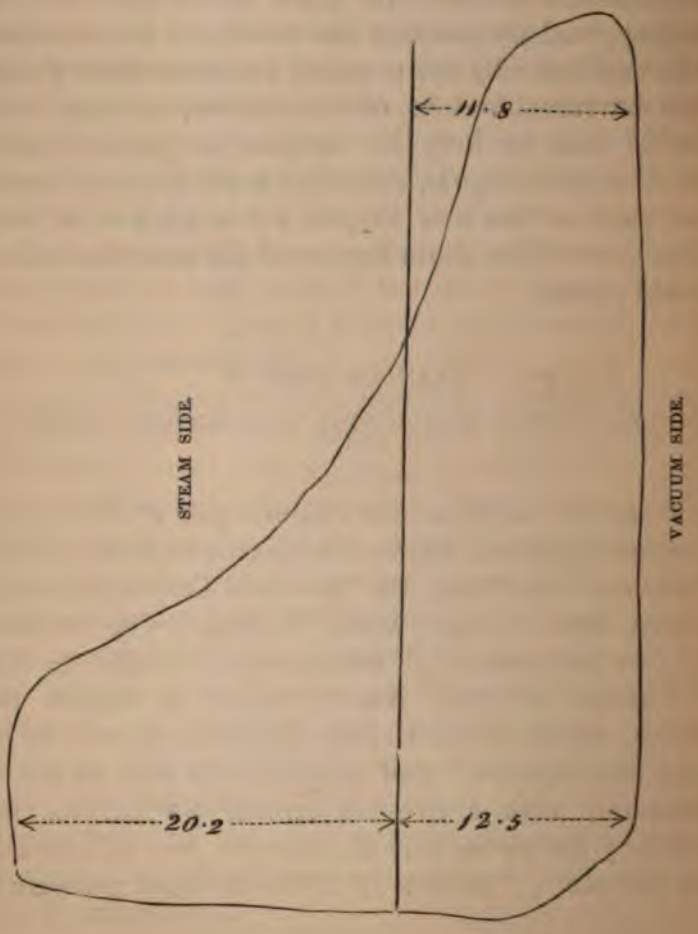
EXAMPLE FROM A DIRECT-ACTING HORIZONTAL CONDENSING ENGINE.

Diagram No. 82 is from one of a pair of Horizontal Condensing Steam Engines belonging to Messrs. JOHN CROSSLEY AND SONS, the renowned Carpet Manufacturers, Dean Clough Mills, Halifax. The Engines are, in principle and construction, similar to the one shewn on plate No. 3, except as regards the valves, which, in the Halifax Engines, are worked by gear and tappets. The cylinders are each 40 inches diameter, with a five-feet stroke, 34 strokes per minute; the piston travelling at the rate of 340 feet per minute. Upwards of 20lbs of steam pressure is

brought upon the piston at the commencement of the stroke, cut off at one-third, making a vacuum of 12·5lbs, with condensing water at 100° to condense with. The Engines are working well, and do the managing Engineer (Mr. BAILEY) much credit. That

DIAGRAM No. 82.

Taken from one End of the Cylinder of a Horizontal Condensing Engine.



gentleman has no less than 2,000 horse power under his charge at the various mills belonging to the firm, and more than 30 steam boilers—all of which are fitted with the Patent Compound Safety Valve.

Messrs. CROSSLEYS' works at Halifax constitute the largest Carpet Manufactory in the world; and Messrs. CROSSLEY are the largest employers of skilled artificers. Those who visit these works find the greatest order and regularity, with prompt attention to all enquiries; and those who have an idea of the difficulties generally met with in managing large concerns, can best appreciate the admirable manner in which this extensive establishment is conducted.

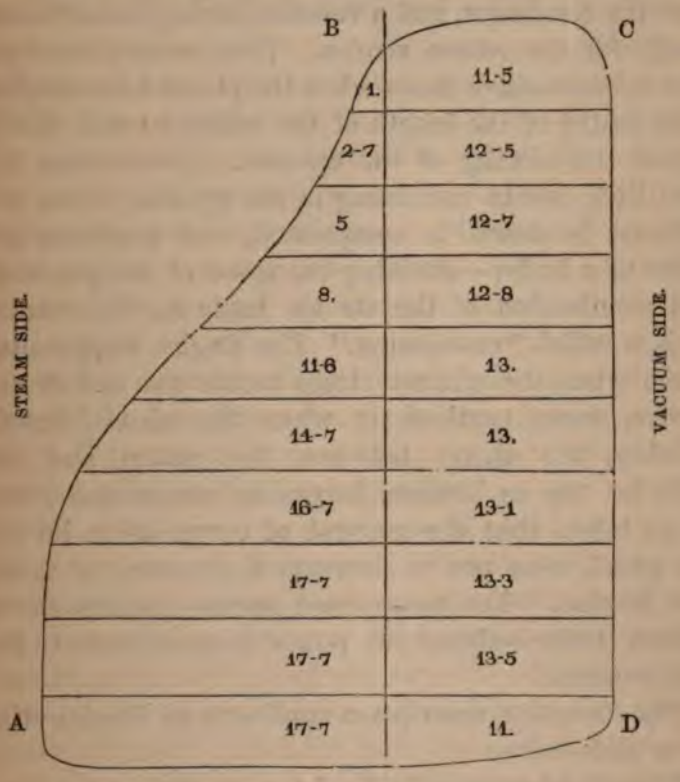
ON THE "SETTING" OF STEAM ENGINE VALVES.

THE proper "setting" of Steam Engine valves is perhaps the most important duty the Engineer has to undertake, involving nicety of calculation and mechanical accuracy, that the strain upon the Engine may be equal throughout the whole length of the stroke. With the assistance of the *Indicator*, the Engineer will be enabled to regulate his valves, and employ the motive power to the best advantage, according to the varying circumstances arising from the peculiar construction of the Engine, the pressure of the steam, or the amount of work the Engine may have to perform. From the fact that these circumstances of construction, pressure, and work of different Engines do vary, it will at once be apparent that one uniform rule for "valve-setting" cannot be laid down. A perusal of the foregoing pages will have shewn, by several of the diagrams and the accompanying comments, that various alterations in the setting of valves were required to improve and perfect the working of the different Engines. Fuel is saved, and power increased—or, in other words, the power generated is rendered most available, when the valves are "set" so as to "beat" at the proper time. This setting will, for the reasons before assigned, necessarily have to be regulated and modified according to the pressure of the steam, the size of the steam ports, and the different degrees of expansion. For example see diagram No. 83.

The corner A is the steam side of the piston. When the crank is at the "plumb-centre" the valve is one-sixteenth of an inch open at the bottom of the V, and this is called one-sixteenth of an inch *lead* on the

DIAGRAM No. 83.

Taken from the Top of a Low-pressure Cylinder with D *Valves.*



steam side. When the piston has travelled one-third the length of the cylinder, the valve has been opened as much as is required, and it is then closed—having cut off the steam at one-third of the stroke, except

the V portion, which closes slowly. By the expansive action of the steam, the piston is forced forward the remaining portion of the stroke. When the piston arrives at the bottom of the cylinder, the crank is at the opposite "plumb-centre." The exhaust-valve is then open two-thirds—in some cases fully open, where the thoroughfares are small. This is usually termed "the lead of the exhaust"; the steam having escaped into the condenser, and a vacuum having been formed ready for the return stroke. [See corners B and C.] The exhaust-valve closes when the piston has travelled nine-tenths of the length of the cylinder: and this is called the closing of the exhaust. [See corner D.] The little steam remaining in the cylinder when the exhaust is closed, is compressed, and performs the office of a buffer—checking the speed of the piston at the termination of the stroke, ready for the return. This is called "cushioning." The Engine works much easier when the exhaust closes before the end of the stroke, more particularly when the piston travels quickly, the steam between the piston and the cylinder top or bottom, becoming compressed—care being taken that the amount of compression be not too great, so as not to decrease the power, or strain the Engine. The compressed steam expands at the return stroke—giving out power proportionate to the compression.

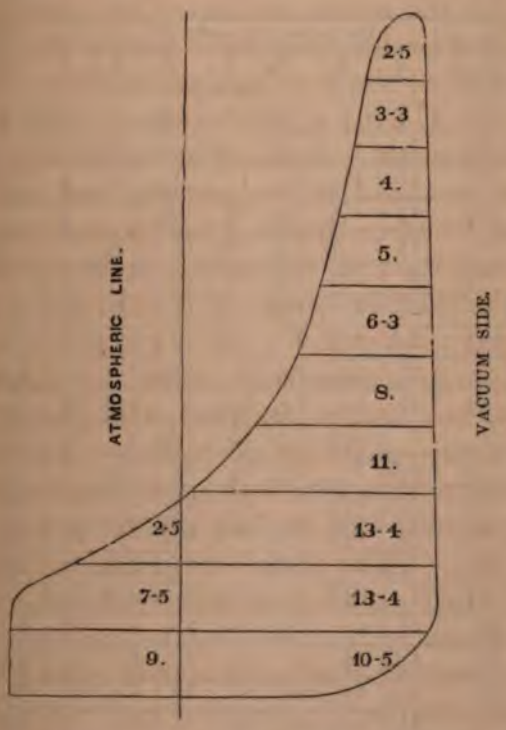
The foregoing description applies to an Engine with D, or slide-valves.

Tappet-valves may be fixed to cut off the steam and open the exhaust at any required distance the piston may have travelled in the cylinder, by having the tappet made movable, or the faces formed as required. In diagram No. 84, the valves are tappet-valves, and

n is cut off at one-seventh the length of the
The expansive principle can thus be made
for the varying amount of the work required,
ving also that valve-setting must vary as the
the Engine and the pressure vary. The

DIAGRAM No. 84.

from the Top of the Cylinder of a Condensing Engine.



um, or double-beat Cornish valves, can be set
egree of cut-off or exhaust. When the steam
f as above, and D valves, or common slides, are
additional cut-off valve, or a great amount of

"lap" is required, and a great pressure in the boiler. "Lap" is added on the steam side of the valve, so that the steam port is only partially opened, and also so that

A TABLE

SHEWING THE AMOUNT OF "LAP" REQUIRED FOR SLIDE-VALVES, WHEN THE STEAM IS TO BE WORKED EXPANSIVELY.

The traverse of the valves being ascertained, and also the amount of cut-off desired, the following table shews the amount of "lap" required.

Traverse of the Valve in inches.	The traverse of the piston where the steam is cut off.								
	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{10}{12}$	$\frac{11}{12}$
	The required "lap."								
2	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$
$2\frac{1}{2}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
3	$1\frac{1}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$	1	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{1}{2}$
$3\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{9}{16}$
4	$1\frac{3}{4}$	$1\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{5}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	1	$\frac{13}{16}$	$\frac{5}{8}$
$4\frac{1}{2}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{3}{4}$
5	$2\frac{1}{8}$	2	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{4}$	1	$\frac{13}{16}$
$5\frac{1}{2}$	$2\frac{5}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$
6	$2\frac{1}{2}$	$2\frac{7}{16}$	$2\frac{3}{16}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$	$\frac{15}{16}$
$6\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{9}{16}$	$2\frac{7}{16}$	$2\frac{3}{32}$	2	$1\frac{13}{16}$	$1\frac{5}{8}$	$1\frac{1}{4}$	1
7	3	$2\frac{11}{16}$	$2\frac{9}{16}$	$2\frac{3}{8}$	$2\frac{3}{32}$	2	$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{1}{8}$
$7\frac{1}{2}$	$3\frac{3}{16}$	3	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{3}{32}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{3}{16}$
8	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{3}{8}$	2	$1\frac{5}{8}$	$1\frac{1}{4}$
$8\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{5}{16}$	$3\frac{3}{16}$	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{5}{16}$
9	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{5}{16}$	3	$2\frac{13}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{3}{8}$
$9\frac{1}{2}$	4	$3\frac{13}{16}$	$3\frac{5}{8}$	$3\frac{3}{16}$	3	$2\frac{13}{16}$	$2\frac{3}{8}$	2	$1\frac{7}{16}$
10	$4\frac{1}{4}$	4	$3\frac{13}{16}$	$3\frac{5}{16}$	$3\frac{3}{16}$	3	$2\frac{1}{2}$	$2\frac{1}{16}$	$1\frac{1}{2}$
$10\frac{1}{2}$	$4\frac{7}{16}$	$4\frac{1}{4}$	4	$3\frac{1}{2}$	$3\frac{5}{16}$	$3\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{3}{16}$	$1\frac{9}{16}$
11	$4\frac{9}{16}$	$4\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{5}{8}$	$3\frac{1}{2}$	$3\frac{3}{16}$	$2\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{5}{8}$
$11\frac{1}{2}$	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{7}{16}$	$3\frac{7}{8}$	$3\frac{5}{8}$	$3\frac{3}{8}$	$2\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{3}{4}$
12	5	$4\frac{13}{16}$	$4\frac{9}{16}$	$4\frac{1}{8}$	4	$3\frac{5}{8}$	3	$2\frac{1}{2}$	$1\frac{7}{8}$

it will close sooner in proportion to the amount of extra "lap." In such case the eccentric requires moving forward in proportion to the extra "lap" added. The

pressure being great, and the steam port having sufficient room, allows the pressure to come upon the piston gradually, during the time the valve is partially open. At page 159 an example is given of what can be accomplished with the D valve and eccentric. The valve in that case does not open more than three-eighths of an inch, the steam being cut off when the piston has travelled one-seventh the length of the cylinder. Where the pressure in the boiler is 30lbs to the square inch, the opening on the steam side, if of one quarter of a square inch area for each nominal horse, will be quite sufficient, or that area of opening for each 22 square inches area of piston. The opening on the exhaust side should be at least one square inch area for each nominal horse. Where the valve box is too short, and where there is not room for "lap," the thoroughfares may be partially made up to answer the purposes of "lap"; (see page 60, and for example, page 192).

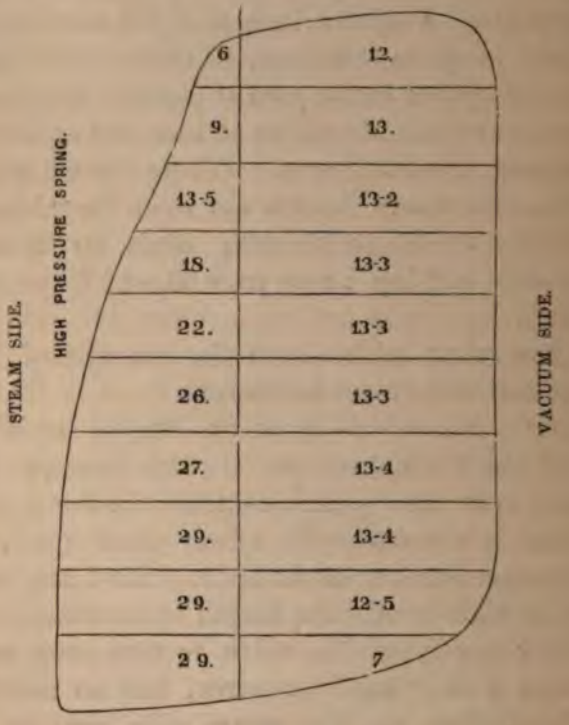
The foregoing table shews the amount of "lap" required for slide-valves in general.

Diagram No. 85 is from an Engine which has valves of the D construction. In this example, when the crank is at the "plumb-centre," the steam side of the valve is one-sixteenth of an inch open, and the exhaust-valve four-fifths open. The latter begins to close at eight-tenths the length of the stroke. The "lap," or cover, of the valve is also long at the end; and this "lap," or cover, has an additional breadth of face on the steam side greater than the width of the two "steam ports." This is for the purpose of cutting off the steam early. In all cases where "lap" is added, the eccentric should be moved forward, in the exact proportion of the "lap,"

—providing there were little or no lead previously,—which will give the same proportion of lead to the exhaust. Short slide-valves, which are in general use for High-pressure Engines, derive advantages from similar arrangements. The principle of "lap," or cover, applies to both under similar circumstances.

Diagram No. 85.

Taken from the Top of the Cylinder of a Condensing Engine.



When the vacuum is bad, the closing of the exhaust requires to be later—because in consequence of there being steam left in the cylinder, uncondensed, the exhaust requires to be kept open longer than would otherwise be necessary.

TWO ENGINES COUPLED, WORKING AT RIGHT ANGLES.

Diagram No. 86 is from one of two Engines coupled together, belonging to Messrs. SELLERS, of Burnley. The pressure of steam in the boiler was 75lbs per square inch The valves are of the common D construction, worked with the ordinary eccentric.

This case shews that valve-setting, with any description of valve, may be made to cut off at any part of the stroke, when the steam in the boiler is of sufficient pressure. The valves and ports are not large, consequently they require an increased pressure of steam. When the steam is reduced to 45lbs per square inch, the Engines begin to lose speed, although there is not more than 21lbs per square inch upon the piston when the Engines are at full speed, because the "lap" on the steam side is so much that the port is not more than one-fourth open when the valve is at the extent of its traverse. The whole value of valve-setting and working expansively consists in having sufficient pressure in the boiler; for in cases where the thoroughfares are small, the pressure makes up the difference. If the steam ports be large, expansion, or cutting off in the cylinder, is effected with less pressure in the boiler, and that, too, without expansion-valves or complicated apparatus. Expansion can be well effected with the ordinary valves, when the steam is at sufficient pressure; and in constructing new Engines there can be no objection to having the valve boxes and thoroughfares so large that the Engineer may be enabled to set his valves in accordance with the varying pressure in the boiler, or the load on the Engine.

Diagram No. 86.

Taken from the Top of the Cylinder of a Condensing Engine.

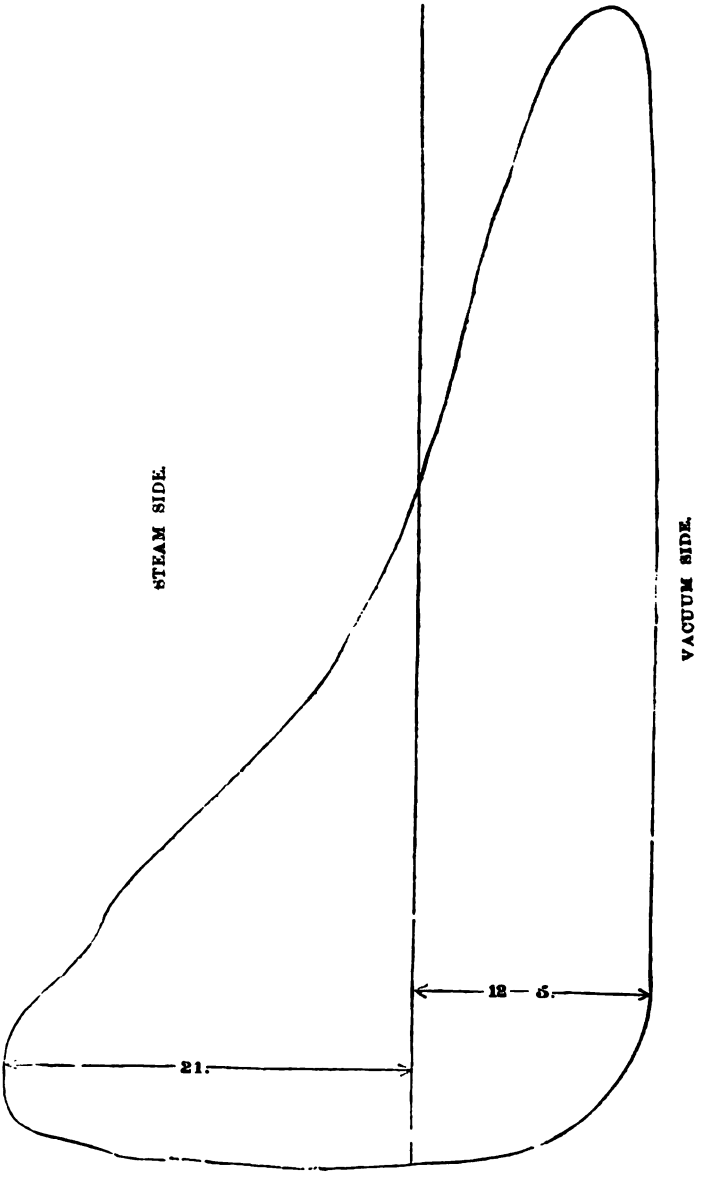


Diagram No. 86 shews that the steam is cut off at one-sixth the length of the stroke, without shock or vibration—because the V in the valve face, as explained at page 133, allows the steam to be cut off early and admitted easily, thus maintaining the pressure on the piston regularly. It will be perceived that the exhaust closes as recommended in the instructions on valve-setting. The steam side is a little late, allowing the cranks to have passed their centres before the steam is admitted on to the pistons. At this pressure the valves are better without lead, so as to open steadily, and admit the steam on easily; for when a valve allows the pressure to come upon the piston easily, it will be taken off in a similar manner. In all cases of valve-setting this is an important point to be attended to—what is termed "easy steaming." In Marine Engines the valves have generally too much lead. Were this point properly attended to, Marine Engines would work much easier, and last much longer.

Cornish, or drop-valves, which are usually opened and closed by tappets, require to be accurately shaped according to the amount of expansion. Expansion also depends upon the pressure of the steam in the boiler, and the dimensions of the ports. There is difficulty in forming steam tappets to raise the valves easily so that the steam may not rush to the piston with too great a force while the crank is passing the centre. To effect this, hoops are fitted to the inside of the seat of the valve, so that when the valve is raised from its seat to admit the steam to the piston, it has to pass through the openings cut in the rims of the valves, as shewn by figure 88, which is a section of an equilibrium-valve, with hoops cast on the under-

side of each valve face. Where the *Indicator* is used and understood, if the valve opens too quickly, the fault can be at once ascertained.

PROPORTIONS OF A PAIR OF 28* NOMINAL HORSE POWER CONDENSING BEAM ENGINES, SHEWING THE MODE IN WHICH THE VALVES ARE SET.

	Inches
Diameter of Cylinders	28
Length of Stroke	60
Length of Steam Ports	14
Depth of Steam Ports	3¼
Cover or Lap of Valve steam side	3
Breadth of Valve face	5⅝
Traverse of Valves	7⅜
Both Exhausts open at each end when the Valve is in the centre	0⅜
Full extent of opening of Valve on steam side	0⅝
Full opening of Exhaust side (being 1¼ inches more than width of Port)	4
Lead of Valve on steam side...	0
Lead of Exhaust at plumb-centre of Crank (being five-eighths of an inch more than width of Ports)	3⅝
Traverse of Piston when the steam is cut off; or near one-third the length of the Cylinder	19
Traverse of Piston when the Exhaust-valve begins to open	48
Vacuum	13½ lbs
Average pressure of Steam and Vacuum	12¾ „
Number of Strokes per minute	30
Working hours per week...	60
Tons of Coal consumed per week	14
Pressure of Steam in Boiler	30 lbs
Injection Water	38°
Water from Hot-well	90°

Valves, long slides, with five-eighths of an inch bevel on the end of Valve, in place of a V exhausting down the centre.

Two Beam Engines coupled at right angles.

Indicated horse power of the two cylinders, 121.

* These Engines are at Bradford, in Yorkshire. They are called in that locality 25 horse power Engines—being three horse less than the calculated rule.

ENGINES WORK AS THEY ARE SET: GOOD OR BAD.

It is often said of an Engine that "it will not work properly, and no one can make it." An inanimate body has no will of its own—is unable to dictate whether it will do this or the other. Steam Engines, of whatever description, "work as they are *set* to work"; and if an Engine does not perform the amount of duty it is calculated for, it is not the fault of the machine, but the fault of the maker, or the Engineer, who does not understand the nature of the machine entrusted into his hands. Where an Engine, not overloaded, does not work properly, the fault lies either in the construction or in the management. If proprietors would but bear this simple fact in mind, when complaints are made that such and such an Engine "will not work," they would speedily see their way to a remedy. Defective construction can be improved—and bad managers are capable of being taught.

Had the amount of money spent in paying Inspectors to report on the leakages of bad joints, and such neglects of management as are always visible to the common observer, been employed in enabling Engine builders and Engineers to learn the first principles of the science of steam propulsion and power, the advantages to all would have been more permanent than they are likely to be under the present circumstances.

SHORT AND LONG-STROKED ENGINES.

THERE is a considerable difference in favour of a long-stroked Engine travelling the same number of feet as a short-stroked Engine; for a ponderous mass in rapid motion has a great momentum. Power is required to stop it, and also to put it again in motion. The laws of motion, of action and re-action, are reciprocal and equal. All the moving parts of a reciprocating Steam Engine are alternately forced from rest, at the expense of the power of the steam. The longer the stroke, the fewer are the changes. The loss of power from change is in the inverse ratio to the length of the stroke; therefore an Engine with a short stroke will require double the power to work itself, compared with one of double the length of stroke, if equal in other respects: and although there may be a heavy fly-wheel, it does not prevent the loss of power, nor even diminish it: but, on the contrary, increases it. The use of the fly-wheel, as is well known, is to equalize the varying powers exerted upon the piston, and to carry the crank over the centres, where the steam has no power; and also to counter-balance various parts of an Engine, particularly the single-acting air-pump. Thus the power absorbed at one portion of the stroke by the heavy body in motion, is partly given back at another portion of that stroke.

In a Single Reciprocating Engine the fly-wheel is indispensable as a regulator of speed.

In addition to the loss of power in a short-stroked Engine, there is also a loss of steam at each end of the cylinder, and in the thoroughfares, in proportion to the number of extra strokes. The loss from this cause alone is a considerable item, where the cylinders are unnecessarily long, and where there is too much space betwixt the piston and the cylinder ends—a point worthy of attention. Fuel, in many cases, is wasted from this cause. From this last described cause, the vacuum of a Condensing Engine is reduced in proportion to the extra quantity of steam to be condensed. It is evident, therefore, that long-stroked Engines will last longer, and require less repair than short-stroked Engines.

For marine purposes, however, the long stroke is not often applicable.

CASED CYLINDERS.

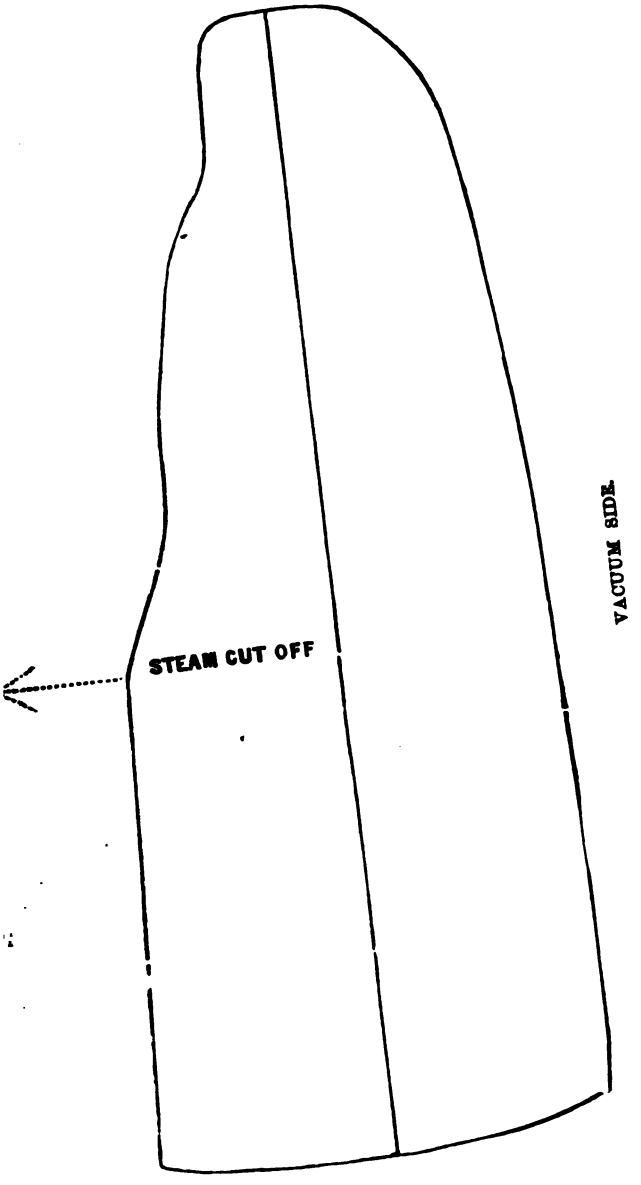
Cased Cylinders were introduced for the purpose of preventing the condensation of steam in the working cylinder, by surrounding it with a "jacket," or case, of metal, a few inches larger in diameter than the working cylinder; the steam from the boiler flowing through the case to the valves, and thence into the cylinder.

As many of these Engines are in operation, it may be well to remind their owners of the great liability of this description of Engine cylinder to become out of order. The accompanying diagram, No. 87, was taken from an Engine belonging to Messrs. Sugden and Sons, Brighouse. To all appearance, the steam was on the full length of the stroke; and this was so, although the valve had shut off the steam when the piston had travelled half the length of the cylinder. It will be observed that on the steam side of the diagram, about half-stroke, there is a decrease of pressure, which shews that the valve was then closed; but pressure was kept up to the end of the stroke by the steam issuing through the bad joints between the case and the cylinder. The steam had a direct escape from the case into the cylinder and condenser, occasioning a serious loss. Proprietors, where cased cylinders are used, should pay particular attention to this probable defect, or great loss may be sustained without any apparent cause. The extra fuel and water used, in some instances, from this cause is enormous.

The object of the "jacket," or case, is to prevent

Diagram No. 87.

rom the Top of a Condensing Engine Cylinder.



condensation in the inner cylinder; and yet, by the mode too often adopted, an increased amount of cooling surface is provided. The object is attained equally as well, and in some cases more completely, by covering the cylinder with wood, felt, or some other non-conducting substance.

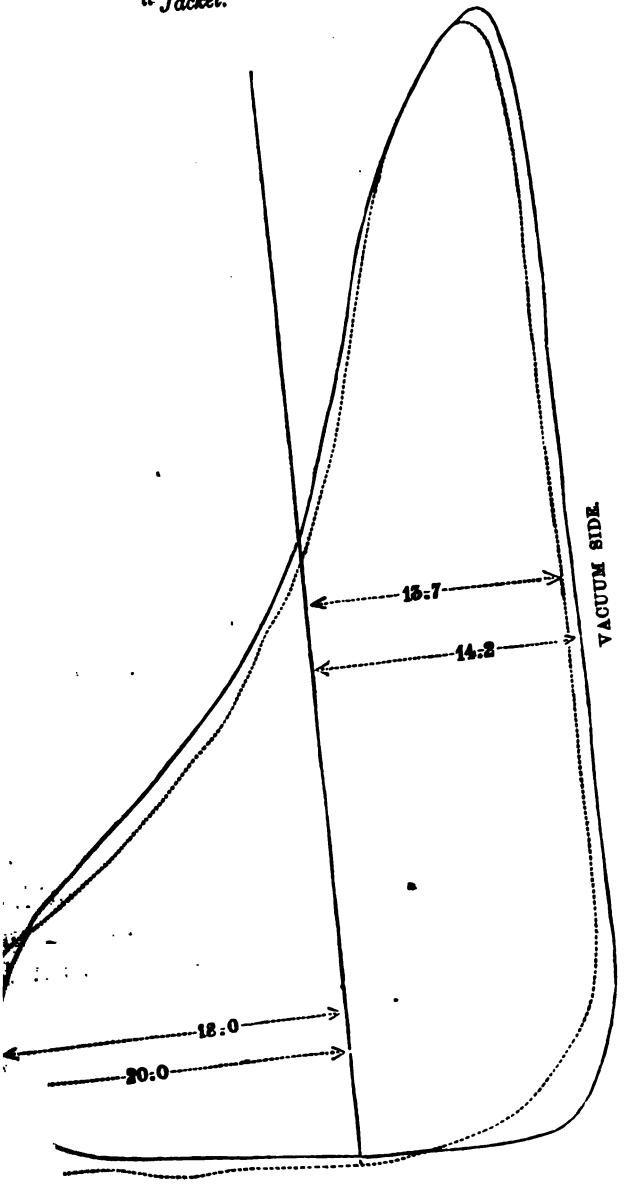
A defect in the joints of the metal case can only be ascertained by the use of the *Indicator*, or by taking off the cylinder cover, and admitting the pressure of steam into the case, to see whether the joints are tight. These joints are often made of borings of cast iron and salamoniac, which, after a time, become oxydized, and crumble away. The joints would be much better closed, and more permanently, were they made with the cement recommended in this work.

Where the steam can be admitted directly into the case at full boiler pressure, the cylinder will be kept up at a higher temperature than the steam used in the cylinder; because in the case the steam is always present, and at the same pressure; while in the cylinder the pressures vary, from expansion and exhaustion. The high temperature of the cylinder thus obtained has a tendency to increase, or rather to keep up, the temperature of the steam admitted into it: and this is an advantage over the ordinary mode of admitting the steam to the cylinder, as the boiler pressure and temperatures are often much higher than those admitted to the piston. But unless the case be strong, there is danger of an explosion. This should be carefully guarded against.

Diagram No. 88 is given to shew the difference in the amount of steam required by a cylinder surrounded with steam at the boiler pressure, and the

Diagram No. 88.

Low-pressure Condensing Engine Cylinder, with a "Jacket."



same cylinder when there is no steam in the jacket. It was taken from one of the Engines belonging to Messrs. HYDE, SONS, AND SOWERBY, of Duckinfield. On examination it will be perceived that when the steam was not admitted to the "jacket," the pressure on the piston was 20lbs above atmosphere, making 13·7lbs of a vacuum. When the steam was admitted to the "jacket" at the boiler pressure, 35lbs, the steam upon the piston was 18lbs above atmosphere, and the vacuum made was 14·2lbs—shewing that less pressure upon the piston was required by 2lbs per square inch at the commencement of the stroke, and that an increased vacuum was obtained of ½lb at the same time. It will also be observed that the closing of the exhaust was not so early as before, because the steam left in the cylinder was not so dense.

This diagram clearly proves that the mode of casing the cylinders adopted by this firm results in a saving of fuel of at least ten per cent. Of course there is the amount of heat lost by radiation from the case to be deducted.

It has been found in practice, that a saving of fuel equal to the amount shewn by the diagram can be effected, where the cylinder is properly cased, as in the instance adduced. There can be no doubt that where the steam flows, it must lose some of its heat; therefore, every care should be taken to prevent such loss, by covering the exposed surfaces with felt, or other suitable material.

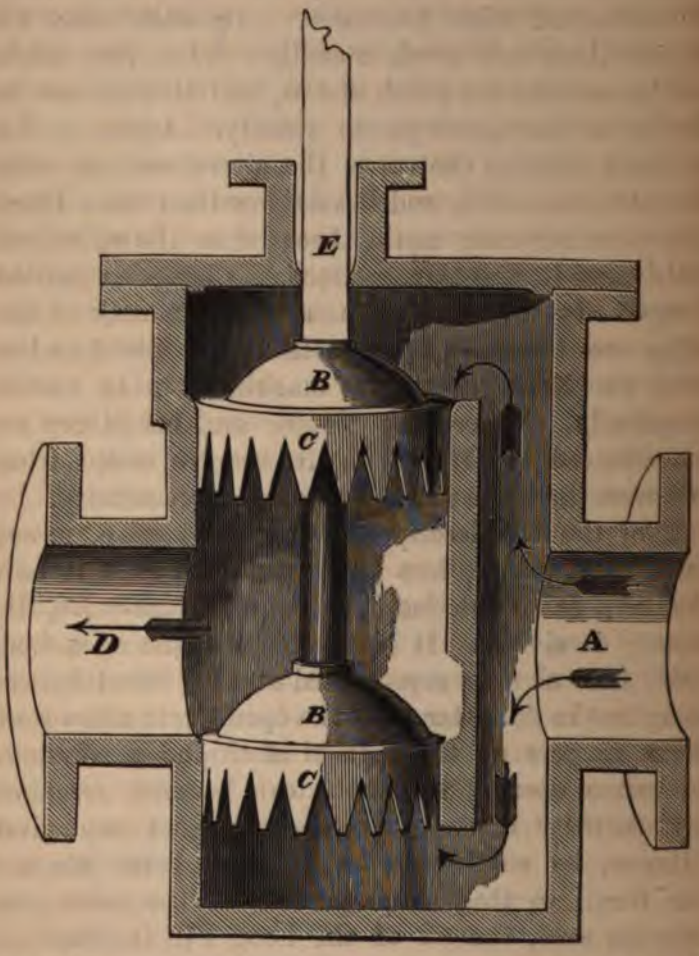
THROTTLE VALVES.

THROTTLE Valves are very often made too large for steam at high pressures. In such case, the Engine does not work steadily; for a very slight opening admits too much steam, and this causes the Engine to jump, and go too quickly. Again, on the governor altering the valve, the alteration may close the valve too much, and the Engine then loses speed. The governor may again throw open the valve, and again close it, and thus produce very irregular motion. Irregularity from this cause—the Throttle Valve being too large—is often ascribed to the fly-wheel being too light, or to the machinery being worked irregularly. Where the Engine and machinery are not balanced, the Throttle Valve requires well setting, and even then there will be constant irregularity.

If of the old description of winged-valve, a new valve is requisite, less in diameter; but if it be a Cornish, or double-faced, or equilibrium-valve, the remedy is simple. It is effected by putting a hoop inside the valve, as represented at Fig. 89—the hoop being less in diameter than the opening, to allow some steam to pass up the outside of the hoop, whenever the valve opens. This hoop can be made to admit any quantity of steam required, and at any given distance, by cutting the edge of the hoop into a ∧ like form, so that in proportion as the valve rises from its seat, the ∧'s of the hoop will increase the opening, and allow the steam to pass through the taper spaces. By these means a proper quantity of

steam can be admitted by the number and size of the openings in the rim of the hoop. The advantage of having Throttle Valves of the proper size must be at once apparent; and as steady turning is of

FIGURE 89.



importance, too much care and attention cannot be exercised in the making and fixing of Throttle Valves,

particularly where the "weight" or the work is not regular. A proper Throttle Valve will prevent the Engine getting "over speed."

Figure 89 is a representation of a DOUBLE-BEAT EQUILIBRIUM THROTTLE VALVE. A is the inlet from the boiler, whence the steam passes to each end of the valve B B, as shewn by the arrows; and then through the valve to the Engine, by the outlet D. The inside valves B B, are connected to the rod E, which rod is attached to the governor by the usual means. C C are hoops cast, or fitted, to the under side of each valve face, and fit loosely into the valve case. These hoops have apertures cut in them of a ∧ form, and of such dimensions, or size, as may be found best suited to admit the steam through in such quantity as the Engine may require, which will be according to the pressure: and the ∧ spaces, or nicks, can be varied accordingly. The steam will be admitted in greater quantities accordingly as the valves are raised from their seats; and as the valves close the steam will be gradually shut off. As the openings, or the ∧ spaces, move up or down, so will the steam be regulated in its admission to the Engine. In the ordinary Equilibrium Valve, without the hoops and the ∧ spaces, when the valves are raised from their seats by the governor the openings of the whole circumference of the valves admit too much steam; and at closing, the valves also close too quickly. This arrangement, in the first place, admits too much steam; and in the second, admits too little—causing the Engine to be very irregular in its revolutions; producing, in fact, *unsteady turning*. As one valve of the Double-beat Equilibrium Throttle Valve is necessarily a little larger than the other, the difference in the

areas, arising from the low valve having to pass through the seat of the top valve, the pressure acts on the under side of the bottom valve and on the top side of the top valve, contrary to each other; but as the top valve is the larger one, the steam having more surface to act upon, closes the valve with a power proportionate to the difference in the areas. There thus requires such an extra amount of power to open the valve as there is extra surface of the top valve over the bottom one.

METALLIC PACKINGS FOR PISTONS AND STUFFING BOXES.

SINCE the introduction of the Metallic Piston, patented by Mr. CARTWRIGHT, in 1797, various modifications of the plan have been introduced, though the principle is unchanged. There can be no question that this invention has contributed greatly to many other improvements of the Steam Engine which have followed; and CARTWRIGHT is entitled to the merit of having introduced what was a decided improvement in itself, and which has facilitated the introduction of others.

Where the cylinder is of good metal, and truly bored, a Metallic Piston will frequently work for years without repair, merely requiring to be kept properly oiled and cleaned. Many attempts have been made to introduce a metallic packing for the piston-rod of the Engine; and this in some instances has succeeded, but not to the same extent as the Metallic Piston. The common mode of packing with hemp, or other elastic bodies, requires great attention, and the packing itself frequent lubrication when the Engine is at work. For reasons of economy and other advantages, the tendency is to work with steam of greatly increased pressure; and, therefore, the old method of packing calls for improvement. One of the best methods hitherto introduced is, to encircle the piston-rod with brass rings cut in two, diagonally, with a little packing at each end, previous to screwing

down the gland. In practice, this method is found to answer well. The packing should be lubricated by a piece of mutton suet placed on the top of the gland. The heat and friction of the piston-rod, in passing up and down, will melt the suet as required, and keep the rod in a properly lubricated state, without much attention on the part of the Engineer, except to renew the suet, which is not often required. By this method a great saving of tallow or oil will be effected, and the friction of the packing on the piston-rod reduced.

There is a great variety of Metallic Pistons. The simpler the construction and the better; and it is essential that the piston be made of good material. Indeed, the metal both for the cylinder and air-pump of an Engine should be of the best quality. Care should particularly be taken that it be sufficiently hard. Where attention is paid to these points in the construction of an Engine, there will be less friction, and less oil required to lubricate the parts.

FEEDING

STEAM BOILERS WITH WATER.

Betwixt the boiler and the Engine-pump, have a self-acting stop-valve, to prevent the water from returning, when once it has passed the valve. It should be so placed, that the water forced from the pump will lift the valve from its seat, and allow the water to pass into the boiler; but when the pump ceases action, the pressure in the boiler should close the valve, and thereby retain the water the boiler has received.

Betwixt the self-acting stop-valve and the pump have a tap, branching from the side of the pipe. When this tap is closed, the whole of the water will pass into the boiler; but in case the water from the pump is more than is required to supply the boiler, the tap can be partly opened, so that one portion of the water forced by the pump may be sent through the small opening of the tap, and conveyed by a pipe to any required place, and the remainder forced through the valve into the boiler. In proportion to the opening or closing of this tap, so will the supply of water to the boiler be less or more. Another advantage of this arrangement is, that when no water for the boiler is required, the tap can be set fully open, and the water will flow easily away, and offer no resistance to the action of the pump. The ordinary method is to have a weighted escape-valve, which requires power to force the water through;

more power in fact than to feed the boiler. The weighted valve also involves great wear and tear. A common inch tap will answer the purpose much better, at a twentieth part of the cost.

The tap may be inserted in the pump bottom, or in any part of the barrel. When the pump is required to force its full quantity of water into the boiler, the tap must be closed. If no water is required into the boiler, open the tap. Air will then be admitted, and the pump will continue to work, taking little power. This is all that is required to regulate the working of the pump, and that too without putting it in or out of gear.

The "Injector," for feeding boilers by its own pressure of steam, is now largely used, particularly for locomotive boilers. The greatest drawback to the use of the "Injector" is, that the water used must be cold, or not more than 80 degrees temperature: otherwise the "Injector" will not act.

ON THE MANAGEMENT OF THE STEAM ENGINE AND BOILER, AND THE DUTIES OF AN ENGINEER.

THE duties of an Engineer are of more importance than at first sight would appear. He ought to be attentive, and conversant with all the details of the construction of the Boiler and Engine entrusted to his charge; otherwise he will be liable to make many mistakes, and may unwittingly cause much damage.

Boilers require careful attention: but under the control of judicious managers, they are perfectly safe, when properly constructed. Entrust their construction and management into the hands of incapacity and ignorance, or let reckless folly and hardihood have their full fling, and death and destruction will almost inevitably follow.

THE BOILER.

The Boiler and Furnace require the especial attention of the Engineer, these being the places where the power he has to apply and regulate is first generated, and from which the most dangerous consequences may arise, either from neglect or ignorance. The following short rules for good management ought to be deeply engraven on the memory of every one entrusted with the care of Steam Engine Boilers, viz:—

I.—All dirt and lumber ought to be kept from the

top of the Boiler, and no person admitted into the Boiler-house, except on business.

II.—It should be ascertained that the Boiler is properly stayed, where stays are necessary, particularly if fixed with angle iron; and the cotters (if any) kept up, and repaired as they are worn down; and it should also be seen that all fixings attached to the Boiler are well riveted on, and good joints made with proper cement, as recommended in this work, [see index] free from injurious compounds detrimental to the metal. All leakages ought to be prevented, or they will soon destroy the Boiler. The flues and the surfaces exposed to heat should be kept clean. Soot and dirt are non-conductors, and cause a loss of fuel, besides decreasing the power of the Boiler.

III.—See that the feed-valve is in good working order: see also that the float (if any) and glass-guage are well attended to. If a self-regulating feeding apparatus is used, it should be closely watched, and on no account be implicitly trusted. Self-feeders to Boilers are liable to get out of order, from friction in stuffing boxes, from dirt, and from other similar causes. Ascertain that the pipes and taps of the gauge are not made up with dirt or scale. If guage taps alone are used, do not rely upon them to test the height of the water in the Boiler. If the water be below the tap, the moment the latter is opened to test the height, the water in the Boiler primes, and rushes to the tap, and shews water when the Boiler is actually short—particularly where great pressure is used. Gauge taps have been the cause of many Boiler explosions, from having deceived the attendant. Where a float is used, see that the float wire is not

strained, or worn to a shoulder, but kept free in the packing; and when worn smaller at the foot where the wire passes through the Boiler, see that it be renewed with a small wire—the smaller the better. Where steam is at a pressure above 10lbs to the square inch, the common float is of little use. In most cases with high steam, they are positively dangerous, and ought not to be trusted. Stop-valves, or other spindle-valves, should be constructed so that the thread on the spindle is *outside*, and may be seen at any time. This may be effected by means of a bridge-casting attached to the part through which the spindle-thread passes.

IV.—Be provided with means to prevent the steam getting to a greater pressure than fixed upon. Should the water from any cause become deficient, the safety-valve should let off the steam and stop the working, independent of any control, until water is again supplied in the required quantity; thus saving the Boiler from explosion. Often ascertain that the safety-valve is properly adjusted. Be particular that the spindle or guides (if any) have sufficient room to work, and also to prevent the parts adhering. In no case have a stuffing-box or spring to a safety-valve.

V.—Let the length of the safety-valve lever be as short as possible, to prevent the extreme pressure you are working at from being increased with the same weight. Let the joints of the fulcrum be brass, or some other metal that will not corrode, or cause the parts to oxydize and become fast. The fittings on the Boiler should be taken to pieces at least once a year, cleaned, re-fitted, and adjusted. This will prevent the parts becoming magnetized, and adhering to each other.

VI.—Whenever, from any cause, the Boiler-plates become over-heated, *open the damper and furnace doors to the full*, that the cold air may cool the Boiler. Closing the damper *increases* the heat in the flue, and by that means the danger is increased. Lead plugs or fusible metal inserted in the flues, do not melt at the temperature required, after being in use a short time; therefore place no reliance upon such contrivances. Above all, do not admit water into the Boiler or relieve the pressure *suddenly;* as either will cause a violent agitation or foaming of the water—and this, washing over the heated plates, will generate more steam than the safety-valve can discharge, creating most imminent danger of an explosion. Under extreme circumstances of this nature, the water sent into the Boiler, or that brought into contact with the highly heated surface, will flash into high steam, just as if a quantity of gunpowder had been ignited within the Boiler, tearing everything asunder. The starting of the Engine is quite sufficient to produce a violent agitation of the water by the pressure being relieved when the Boiler is overcharged with heat, and disastrous consequences may be the result. Above all, do not depend on open column-pipes inserted in the Boiler, as a means of safety from explosions; for though they will relieve at times from over-pressure—to the great danger in such cases of running the Boiler empty—they are positively dangerous from another cause. It has been ascertained, by experiment, that though the water in the Boiler may be reduced so low as to lay some of the plates bare to the action of the fire, the water from the pipe will not descend below a certain point to equalize the pressure, but will hang from the bottom of the pipe

in the form of a cone. Under these circumstances should this cone from any cause, agitation or otherwise, become detached from the end of the pipe, and be dispersed over the heated plates, the consequences above pointed out are almost inevitable. In fact, these open column-pipes are no safeguard whatever against a Boiler becoming low in water, or, indeed, practically empty.

VII.—See that the dirt in the Boiler is well blown out. Some descriptions of water will require the Boiler cleansing every three hours, others not so often —according to the quality of the water. If this point be attended to, the Boiler will wear much longer, and seldom require opening; the consumption of fuel will also be much less. In Marine Boilers, the blowing out at stated intervals prevents the deposit of salt and lime, and is the only thing required to keep the Boilers clean.

VIII.—Have the feed water for the Boiler as hot as possible, and sent into the Boiler *near the surface* of the water inside. The cold water will descend, and before arriving at the bottom it will become heated; thus tending to keep the Boiler at an even temperature. When the water is sent into the Boiler near the bottom, it does not rise until it has become heated; and this last mode of feeding tends to keep the Boiler bottom cooler than the other portions, causing the plates at the bottom to break from unequal expansion and contraction—an evil which ought to be avoided. The Cornish, Double Fire-box, and Tubular Boilers are more subject to this evil than most others. The Engineer should therefore have the feed-pipes raised in the Boiler, when they are inserted in or near the bottom, otherwise the Boiler may break in the centre,

and cause much loss or damage by the parts of the Boiler separating.

IX.—When there are two or more Boilers, with feed-pipes connected together, without a self-acting stop-valve between each, shut off the feed-valve to each Boiler during the night, or whenever it is not working; the water being liable otherwise to empty itself from one Boiler into another, leaving one of the Boilers nearly empty; more particularly where there are Boilers working at different pressures. A self-acting stop-valve is in the last case absolutely necessary.

X.—Where junction steam-valves are used, or a valve placed between the Boilers and the main steam-pipe, see that the valve-spindle is one without a weight or screw, and take every precaution to prevent the valve from being weighted down when the steam is up. Sometimes the safety-valve is on the steam-pipe; in that case junction-valves are dangerous, where they can be fastened down. In the stop-valve for the Boiler, the spindle should be constructed with a screw-thread, and be *outside*. The nut for the screw can be fastened in the centre of a bridge cast to the valve-box lid. Where the screws are inside, difficulties often arise. In all pipes fixed to the Boiler, have them so arranged that the condensed steam will drain back to the Boiler, and not go through the Engine. A great saving will be thereby produced, the hot water supplying the place of cold, according to the amount condensed.

XI.—Where there are two or more Boilers, do not keep any one out of action longer than absolutely necessary for cleansing or repairs. A Boiler wears out faster when not in use, by oxydizing and corroding

than if moderately worked. It will be found more economical to work with "extra Boiler room," than to have one or more "standing." The furnaces will be easier stoked by working a thick fire, allowing the heat to accumulate, thereby maintaining a high temperature in the furnace with slow combustion. By this mode of firing, the furnaces will last much longer, and in the case of a Fire-box Boiler, the plates in contact with the hot fuel will generate steam much quicker, with less labour and attention, there being an extra amount of absorbing surface in contact with the fuel with the same area of grate.

XII.—Where the Boilers are set in brickwork, *do not use lime in contact with the iron.* In setting the bricks, use fire-clay, or common clay. Lime with damp, eats away the iron quickly; therefore do not use it at all about the metal of a Boiler. Where a "midfeather" is placed under a Boiler, it ought to be of cast-iron, in the form of a ∧ for the Boiler to rest upon. Should any leakage take place, there will be little surface for the water to lodge on. Whenever the flues are cleaned, examine the exterior and interior thoroughly. Do this also whenever the Boiler is let off.

XIII.—Have a good steam gauge to the Boiler; one that cannot be tampered with, and one not liable to get out of order. Place it in a situation where the cold or frost cannot affect it. A column of mercury is the truest indicator, when used without a floating stick, or "steam peg." "Pegs" can be made longer or shorter, to suit the convenience of the Fireman. Avoid all enclosed metallic springs, India-rubber washers, bent tubes, or round dial gauges, to indicate pressure. Do not depend upon them; for the springs

corrode, the bent tubes lose their elasticity, India-rubber washers become indurated, and the indications of the gauge will vary accordingly. There are various forms and makes of steam gauges; but many of them are nothing better than philosophical toys.

THE FURNACE.

After seeing that all the fittings of the Boiler are in the best possible order, turn attention to the Furnace. There is more required here than the simple process of feeding the fire with fuel. In the first place, the nature of the coal should be ascertained, whether or no it be of a coking description. If it be, the grate bars will require to be more open than for coal of a light and gaseous nature. Adjust the grate surface to the heating or absorbing surface of the Boiler. This will greatly depend upon the quality of the fuel and the druaght, and the quantity of steam required. If the draught be good, work a thick fire; but do not break the coal except it cannot be got in at the Furnace door, taking care to feed the Furnace on one side, not covering more than one-half the grate at a time. When that is sufficiently coked, feed the other side, putting plenty on at a time, leaving the middle of the Furnace much lighter and thinner of fuel than the sides, and keeping the grate bars well open. This mode of stoking—placing the coal on one side at a time—will prevent the formation of a great portion of the smoke which would otherwise result, and also produce a more steady heat. The coal so placed will partially damp that side of the Furnace on which it is placed; therefore the necessity

of stoking the Furnace when the steam is up. From this method of firing, the gas generated will be given out slowly. The greatest quantity of air will pass through that portion of the grate where the fuel is most consumed, and where the coal has not been made small by breaking, leaving the interstices wide; and as the oxygen of the air will be in sufficient quantity, if this mode of firing is adopted, to unite with the gas as it is extracted from the coal, a continuous flame will be kept up, and smoke prevented. When one side of the Furnace so fired is sufficiently coked, raise the burning fuel gently with the poker, but do not break it into pieces. At the next firing place the coal on the other side of the Furnace, and similar results will follow. Replenish first one side, and then the other: and continue to do so in the working of the Furnace, keeping out the cold air as much as possible. Keep the Furnace door open no longer than is absolutely necessary; and place your coal before firing near to the Furnace, that there may be no loss of time in charging the fire. All cold air coming in contact with the Boiler lets down the temperature, and does harm. To ensure that the coals be sufficiently near, and that the Stoker cannot have them too far from the Furnace doors, it is best to erect a barrier in front of the Boiler, at about six feet distance, with an opening at the bottom. The coals behind this barrier will have to be up to the opening at the bottom. This mode will enable the Stoker to charge his Furnace with fuel without moving from the front. He will thereby take less time, and be able to close the door earlier than if he followed the ordinary modes of stoking.

If a Double Fire-box Boiler, fire each Furnace

alternately, in the manner above described, and as illustrated by the engraving, where A and B represent the sides of the fires last stoked, with the gas given out from the new fuel, mixing with the air which passes in the greatest quantity through the thin portion of

the fire, as indicated by the arrows. Being thus mixed with air at a high temperature, the gases ignite, and comparatively thorough combustion is secured, preventing smoke and saving fuel. This mode of firing is applicable to most Furnaces, whether single or double fire-box, or with the fire wholly beneath the boiler.

oal be of a light gaseous description, burning
ashes, work the Furnace in the manner above
with the bars a little closer together.
here is a bad draught, the Furnace will
orking differently, placing a little coal on at
of firing, equally over the grate. But this
firing is, generally speaking, not an econo-
. Much however depends on the nature and
f the coal, for there are some descriptions
ll not fire in any other manner. By this
de of firing, the gas is extracted from the
er than the oxygen passes through the grate
e it. In that case a great portion of the
s up the chimney in the form of smoke; and
ace door having to be often opened to
the fire, admits large quantities of cold air,
ols the Furnace and the flues: an evil some-
lified by partially closing the damper when
dirty Furnace will have a similar effect in
moke. If the grate be covered with clinkers
, the oxygen is prevented from entering, and
converted into smoke. In fact this is one
st prolific sources of the "smoke nuisance."
means avoid having a dirty ash-pit. A pit
l of ashes is a sure sign of bad management.
necessary to keep the ash-pit of a Furnace
cool, and the air as dense as possible, as it
the fire with fuel. If the ash-pit be hot, the
nds the air, and the Furnace will require
uantities to pass for the amount of oxygen
ould be supplied by less quantities of cold
ese greater quantities impair the draught.
nvenient, use water for the bottom of the
llowing it to remain to quench the ashes as

they fall from the Furnace. The evaporation will tend to keep the grate cool. Have (if possible) some water near the Furnace, so that when cleansing the fire you can cool the slag, that you may remove it early. These things properly attended to, will cause the Furnace to wear much longer, and also save fuel. There will likewise be less labour to produce more steam in the same time than a slovenly mode of stoking would produce.

A great body of fire will evaporate more water with a less proportion of fuel than a small and thin fire. The greater the intensity of the fire, the more steam will be generated with the same amount of fuel. Where there are a number of boilers, it is important that the duty of stoking should be properly attended to; and as smoke is a great nuisance easily prevented, its prevention is a duty which every Engineer ought to attend to.

With regard to the consumption of smoke, it may be observed that the heat of one fire coming into contact with the gases of another fire behind the bridge, or in what is called "the combustion chamber," does not consume the smoke. Smoke cannot be consumed after it has left the Furnace, unless air be admitted to mix and ignite with it, and the gas must also be of sufficient temperature to cause ignition. The best part of the Furnace in which to admit air to ignite the gas, is near to where the gas is generated. If additional air be required to that which passes through the grate, it is best admitted at the bottom of the Furnace door, or through the dead-plate, as illustrated by the engraving on the next page, which represents a dead-plate pierced with apertures for the admission of air through and amongst the coking coal. This

method of admitting air has been much resorted to since the first edition of this work appeared. The method is recommended by the "Lancashire Association for the Prevention of Boiler Explosions;" and the author, having had twenty years' experience with all and every kind of smoke-prevention apparatus, is able to say that he never found anything to answer so effectually as the mode of firing before described and illustrated, in combination with this mode of admitting air at the Furnace door or through the dead-plate, when the requisite amount cannot be got through the ordinary grate.

All Furnace doors should have a number of half-inch holes cast or drilled through, independent of all other contrivances. The air passing through these holes into the Furnace keeps the doors cool, and assists combustion.

The opening between the grate bars is an important point to be attended to. If these are not sufficiently wide, the Furnace becomes a retort for the destructive distillation of coal, the gases passing off in the form of smoke for want of a sufficient quantity of air to consume them as they are generated. Smoke is often produced from the bars being too close together; and it is false economy to suppose that fuel is saved by having the apertures between the grate bars too small. A proper thickness of the bars, also, is a requisite in practice. These have been found to

answer best when from one-half to three-quarters of an inch thick.

Attention to the foregoing rules, viz:—careful firing, clean grates, wetting the small coal, placing plenty on at a time, firing alternately at the sides, a clean ash-pit, and, above all, a good draught, will, for all practical purposes, prevent the formation of smoke. That attention will also prevent the waste of fuel, save time and labour, and reduce wear and tear. Of course under different circumstances modifications will be required, varying accordingly; but by the adoption of the principles herein laid down, the "smoke nuisance" would soon cease to be cause of complaint.

THE ENGINE.

The Engine itself requires but little attention when in good order, except the ordinary routine of packing, cleaning, and oiling the working parts, and occasionally adjusting the cotters, which on no account ought to be neglected.

Indicate the Engine every day. Perform the operation when the load is on. Work up the diagram, and place it in a book, with the date, for reference at any future time. This mode will denote the difference of power required under different circumstances; and also make known any defective working, whenever any part of the Engine gets out of order, or whenever any shafting or machinery is taking more power at one time than another.

It will not be necessary to work up the diagram each time. When the indicated horse power has been once ascertained, the following rule will be found to

be correct enough for all practical purposes, and much more ready than working the diagram each time thoroughly out.

EXAMPLE:

Diagram No. 2 represents 99 horse power, when the friction of the Engine and shafting is deducted.

Divide by the average pressure,
of No. 2 diagram... 12lbs) 99 ($8\frac{1}{4}$lbs horse power for each pound
96 pressure per square inch upon
— the piston.
3 remains; this being $\frac{1}{4}$ of 12, it makes
the total to be $8\frac{1}{4}$ horse power.

If a diagram be taken from the same Engine, with less, or more, average pressure, multiply the average pressure upon the piston by 8·25, to ascertain the horse power the Engine is then exerting.

EXAMPLE:

15lbs the pressure upon the piston.
8·25 the number of horse power for each pound
— pressure upon the piston.
75
30
120
———
123·75 horse power.

The horse power being $123\frac{3}{4}$lbs. It matters not whether the horse power be required independent of the shafting and Engine, the calculations are made the same. Each Engine indicated will require the first diagram taken to be figured up, and worked out in the usual way, to obtain the horse power the Engine is turning.

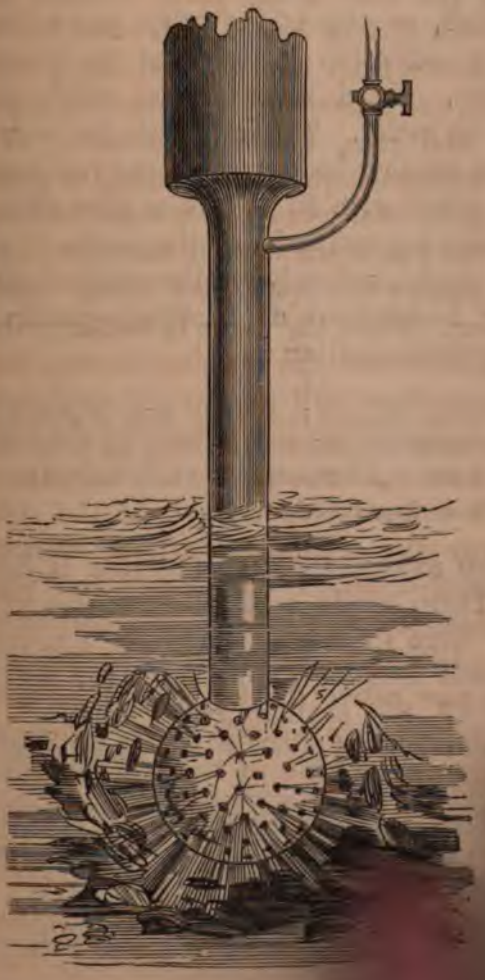
Use a thermometer to test the temperature of the condensing water, which ought not to exceed 120 degrees of Fahrenheit. Work as much below that

temperature as is consistent with the supply of water to the boiler, and the quantity the air-pump will discharge—keeping the delivering-valve closed as long as possible, for the reasons before set forth. If the water in the air-pump thump and plunge, a small air-pipe inserted in the pump lid will often prove to be a remedy.

Should the rose of the pump become choked, or stopped with dirt or leaves, as is often the case when water is drawn from rivers, pools, dams, streams, and even wells, the accompanying sketch of a pump-head tail-pipe and rose, illustrates a mode of clearing the rose without stopping the pump, or getting down to the rose to clear away the accumulations. Insert a small pipe and tap under the low valve, or "clack," of the pump—the pipe end being open to the atmosphere. When the pump is working, the tap will be closed, of course. By opening the tap, the pressure of the atmosphere will act upon the column of water in the tail-pipe of the pump, betwixt the low "clack" and the rose. The water in the tail-pipe will rush back with a force proportionate to the column, and force away the accumulations, as shewn by the engraving, No. 90. If the pump be not placed much higher than the rose, the column will be short, and have very little force to drive off the debris. In that case the pipe above the tap should be carried to an elevated cistern, containing water. Then, when the tap is opened, the rush of water will clear the rose. In performing these operations, no stoppage will be required. The attendant has simply to open the tap for a short time, while the water descends, and then close it again. This little simple apparatus is calculated to save much time and trouble; for in some

he covering of the rose by refuse matter is a
nnoyance, which, under the old method of
g, involves a waste of time and labour.
eady working of the Engine is sometimes
by the connections between the governor and

FIGURE No. 90.



the valve being too weak; in that case the parts spring and give way, and vibration is the consequence. The throttle-valve being too large, has a similar effect, and is often the cause of Engines working unsteadily. Throttle-valves, regulated by pumps, vary with the pressure of the atmosphere; for the water is "high" or "low," in accordance with the varying pressure.

Should the crank-pin, or the bearings of the fly-wheel shaft, or any of the other parts become hot, particular attention is required to prevent their destruction. Lead filings mixed with oil will be found to be useful. The lead coats the bearings, and interposes another body between the rubbing surfaces. Sulphur mixed with oil has also a good effect.

The following recipe for cooling necks of shafts will be found useful, not only for the crank-shaft, but for all other descriptions of shafting—particularly the feet of upright shafting:—

16lbs of Tallow, dissolved in a vessel. 2¼lbs of white Sugar of Lead. When the Tallow is melted, but not boiling, put in the Sugar of Lead, and let it be dissolved. Then put in 3lbs of black Antimony. Keep stirring the whole mass till cold.

It is an axiom, that "prevention is better than cure." There would seldom be heating of necks of shafting, were those necks made of a proper length. They should in all cases be *twice* the length of the diameter of the shaft. The "brasses," or steps, should be made of good metal—composed of three parts of copper to one part of tin. "Good brasses" involve, because they secure, a saving of oil, and also power. More attention ought to be paid than is generally the case, to the quality of the metal of which steps, or bearings of shafting, are made.

oper attention to all packings, to prevent the
steam or water. Such leakages often cause
struction than ordinary wear and tear. If
tion cock or the condenser be leaky, the
l get into the cylinder when the Engine is
in consequence of the partial vacuum; and
ng afterwards, the water will in all proba-
the means of breaking the beam or some
t. Care should be taken that all taps con-
th the cylinder are closed when the Engine
, except a small tap connected to the con-
nd whenever the Engine is stopped, this tap
e opened to destroy the vacuum—or the
y, from some cause, get into the cylinder.
ng the Engine, close the tap. This simple
ent will be the means of saving much
nd probably prevent break-downs. This tap
be found useful in stopping the Engine at
red angle of the crank, by admitting the air
ndenser and destroying the vacuum.

he pipes and cylinders clothed with a non-
g substance, to prevent the escape of caloric
steam. It will pass away very quickly if
e not used to retain it, causing a loss of fuel.
vacuum-gauge fixed near to where you pass
gine-house, that the quality of the vacuum
ndenser, or the amount of the uncondensed
ay be easily examined. The vacuum-gauge
one that shews the pressure of the uncon-
eam left in the cylinder, and the pressure of
sphere at the same time, or otherwise it
e ascertained by the *Indicator*, when the
aries, whether it be from the pressure of the
re or the deficient vacuum of the Engine.

In some states of the weather the pressure of the atmosphere will be under 14lbs to the square inch, and at other times it will be upwards of 15lbs to the square inch. Steam may be 20lbs above the atmosphere; but when the pressure of the latter is 14lbs, the steam will be 34lbs; but if the pressure of the atmosphere be 15lbs to the square inch, the steam in the boiler will be 35lbs; and so on in proportion to the varying pressures of the surrounding medium.

Have proper taps fitted to the top and bottom of your cylinder, that you may indicate your Engine with ease. By indicating each end you will see if your valves are equally set. Both ends can be indicated on one paper. (See page 164.) After using the *Indicator*, clean it well: a dirty *Indicator* is an indication of a slovenly Engineer.

HOW TO CALCULATE FROM A DIAGRAM THE QUANTITY OF STEAM USED BY A STEAM ENGINE

For illustration, we shall first take diagram No. 1, where the steam is not expanded.

That diagram shews that the pressure of the steam at the beginning of the stroke, is 12·2lbs above atmosphere, and at the termination, 10lbs: the difference in pressure from one end to the other being 2·2lbs. This difference is caused partly by the closing of the valve, and partly by the cold cylinder condensing a portion of the steam admitted. To ascertain the quantity of steam the cylinder is charged with, we must take the pressure at the termination of the stroke, or at the point where the exhaust begins to open and reduce the pressure. In diagram No. 1,

the steam is on for the full length of the stroke; therefore we have at once the exact quantity the cylinder is using—10lbs of steam above atmosphere, and 12·3lbs of a vacuum; making 22·3lbs of steam available, out of the 25lbs of steam-pressure used. For this calculation, we take the atmospheric pressure at 15lbs—but it is oftener at 14·3lbs, than at 15lbs.

Suppose there had been a vacuum of 15lbs, then the whole pressure of the steam applied would be available as a motive power, viz. 25lbs.

We will now take No. 2 diagram. At the beginning of the stroke, there is a pressure of steam 17lbs above atmosphere, reduced by expansion to 6lbs below atmosphere at the end of the stroke: and there being 13lbs of a vacuum, it follows that there has been expended, at each half stroke, a cylinder-full of steam at 9lbs pressure to the square inch: but only 7lbs of that has been available for giving out power.

Another example is presented by diagram No. 45. There is 17lbs pressure of steam above atmosphere at the beginning of the stroke; and this is expanded down to 10lbs below atmosphere, the Engine making a 13lbs vacuum. Thus, No. 45 Engine is using only 5lbs of steam per square inch, and 3lbs of this is the available power.

It must be understood, that whatever may be the pressure of the steam in the cylinder *at the commencement of the stroke*, that is no criterion as to the quantity used. The quantity used will be according to the pressure at the termination of the stroke—or at the opening of the exhaust—taking into account the amount of vacuum, as it appears on the diagram.

HOW TO CALCULATE THE EFFECTIVE PRESSURE OF STEAM ON THE PISTON AT THE END OF THE STROKE, CUT OFF AT ANY DISTANCE, WHEN WORKED EXPANSIVELY.

RULE.

Divide the length of the stroke in inches by the distance in inches the piston has travelled to the place where the steam is cut off; then divide the pressure of the steam with the average vacuum added to the first quotient: the second quotient will be the pressure per square inch on the piston at the end of the stroke.

EXAMPLE.

Length of stroke, 60 inches. The steam cut off at one-third, or when the piston has travelled 20 inches. The pressure of steam on the piston, 25lbs. Average vacuum, 12·5lbs—equals 37·5lbs. Here we have 60 inches, which, when divided by 20 inches, equals 3; and 37·5lbs divided by 3 equals 12·5lbs, the pressure per square inch upon the piston at the end of the stroke, or 2½lbs below the pressure of the atmosphere.

The same law holds in all other proportions, and with all other gases and vapours, provided the temperature remains unchanged. If the valve of an Engine be closed when the piston has travelled one-fourth of the stroke, the pressure upon the piston at the termination will be one-fourth the pressure it was at the commencement of the stroke; and the intermediate pressures vary from the highest to the lowest, in proportion to the distance travelled by the piston to the place where the steam is first cut off.

Air or gas heated from 32 degrees to 212 degrees, will expand 375, or $\frac{3}{8}$ of its bulk. It follows that for every degree of heat, air or gas expands $\frac{3}{8}$ of $\frac{1}{180}$, or $\frac{1}{480}$ part of its bulk at 32 degrees; thus shewing how important it is to place a gas meter in a cool situation or to surround it with water, that the gas may not expand; for the meter will then register more than intended. The denser the gas, the less consumable quantity the meter registers. Steam should also be surrounded by a non-conductor of heat, to keep up the pressure; for in proportion to the difference in temperature of the steam and air, so will the absorption be more or less, which will have to be made up by an extra quantity of fuel. It therefore follows that if the cylinder of a Steam Engine can have the temperature raised above that of the steam acting on the piston, its pressure will be increased in the cylinder—a point of no mean importance. This can be effected by the full pressure of steam from the boiler surrounding the cylinder, in a case, or otherwise. At Messrs. HYDE, SONS AND SOWERBY's this is carried out by the means indicated, as before shewn—and a saving of fuel is the result. The steam from the boiler at full pressure, 35lbs to the inch above atmosphere, surrounds the cylinder in a case. The temperature of that steam is 283·2°. The steam upon the piston is 20lbs above atmosphere, and its temperature only 260·9°. As this steam expands down its temperature decreases, but the high temperature of the cylinder is kept up by the means described. Condensation of steam in the cylinder is thereby prevented.

TABLE:

SHEWING THE INCREASE AND DECREASE OF THE STRENGTH OF IRON AT VARIOUS

Comparative view of the influence of High Temperatures on the strength of Iron, as exhibited by 73 experiments on 47 different specimens of that metal, at 46 different temperatures, from*

No. of the comparison.	Temperature observed at the moment of fracture	Mark of the bar on which the trial was made.	Strength at ordinary temperatures.	No. of experiments at ordinary temperatures.	Strength at the temperature observed.	No. of experiments at high temperatures.	Amount of variation from uniformity in the cold experiments.	Effects of the heat expressed in parts of the original strength.	REMARKS.
1	212°	137	56736	1	67939	1		+ ·197	
2	214	133	53176	1	61161	1		+ ·150	
3	394	58	68356	1	71896	1		+ ·052	
4	394	148	65143	1	69752	1		+ 070	
5	394	23	62646	2	67765	1	·1041	+ ·081	
6	394	125	57182	1	63322	1		+ ·107	
7	394	61	55297	5	61917	1	·2026	+ ·119	
8	396	75	60433	3	62415	1	·0444	+ ·031	
9	440	224D	49782	4	59085	1	·0908	+ ·187	
10	520	224B	54934	4	58451	1	·0992	+ ·064	
11	550	199A	76986	4	79846	2	·0936	+ ·037	The standard for the original strength may possibly be a little too high.
12	550	221A	60518	4	60322	1	·1680	— ·004	
13	552	14	52542	1	55932	1		+ ·064	
14	554	218A	58124	4	60412	1	·0730	+ ·039	
15	554	22	54372	4	61680	3	·1919	+ ·134	
16	560	224E	50528	7	58824	1	·0605	+ ·158	
17	562	224C	53385	5	59623	1	·1919	+ ·104	
18	563	60	60907	4	72588	2	·0460	+ ·191	
19	564	74	51030	5	58824	1	·0764	+ ·142	
20	568	9	67211	2	76763	1	·0601	+ ·042	
21	572	219B	66724	2	66620	1	·0325	— ·002	Standard probably too high for the mean strength.
22	572	49	59607	3	62278	1	·0878	+ ·045	
23	572	222B	56165	4	60117	2	·1550	+ ·070	
24	573	10	64511	1	67503	3		+ 046	
25	574	231	76071	5	65387	1	·1373	+ ·014	
26	575	220A	54263	4	60988	1	·0280	+ ·124	
27	575	62	58376	3	70081	3	·0262	+ ·200	
28	575	207	51924	5	63825	3	·1225	+ ·229	
29	576	221B	59234	5	66065	1	·1190	+ ·115	
30	576	223B	43386	6	50068	1	·0760	+ ·154	

* Shewing that Iron Steam Boilers become stronger as the temperature increases, up to about 600°, beyond that temperature it becomes weaker. Copper decreases in strength from 56° upwards.

RATURES, FROM TESTS BY THE COMMITTEE OF THE FRANKLIN UTE.

o 1317° *Fah., compared with the strength of each bar when t ordinary temperatures: the whole number of experiments at ter being* 163.

Mark of the bar on which the trial was made.	Strength at ordinary temperatures.	No. of exp. at ord. temp.	Strength at the temperature observed.	No. of exp. at high tem.	Amount of variation from uniformity in the cold experiments.	Effects of the heat in parts of the original strength.	REMARKS.
164	58769	5	66929	2	·1214	+·139	
224A	52406	5	59197	1	·0565	+·129	
223A	45757	5	53465	1	·0896	+·168	
86	62156	3	77163	2	·0986	+·052	
220B	59459	5	62966	1	·0680	+·058	
90	50316	5	57310	2	·2401	+·138	
219A	59530	4	60010	1	·1440	+·008	
16	53543	1	50039	1	·1563	—·067	This experiment was on a part probably defective.
150	59307	5	58181	1	·0644	—·019	
152	57133	3	54441	1	·0507	—·047	
14	52542	1	53378	1	·1310	+·016	
150	59397	1	57903	1	·0644	—·026	
16	56891	1	54819	1	·1563	—·037	
149	56825	2	54781	1	·0234	—·036	
214	59219	1	55892	1	·0413	—·073	
149	56825	2	56644	1	·0234	—·029	
214	59219	1	45531	1	·0413	—·240	
232	58341	2	42401	1	·0446	—·273	
214	59219	2	37410	1	·0413	—·369	
152	58992	1	37764	1	·0507	—·360	
227	53426	6	27604	1	·0330	—·483	
227	53426	6	27602	1	·0330	—·483	The metal was decidedly defective at the point where this fracture was made—flaws visible.
226	54758	2	18672	1	·1147	—·659	
227	53426	6	21967	1	·0330	—·589	
229	55774	3	25620	1	·1102	—·538	The 8th experiment on this bar being taken as the standard, would exhibit the effect—·550.
227	53426	6	21910	1	·0330	—·589	
226	54758	2	21298	1	·1147	—·611	
226	54758	2	20703	1	·1147	—·622	
226	54758	2	18913	1	·1147	—·654	

Mean—57525

TABLE.

EXPANSION OF AIR BY HEAT:

SHEWING THE INCREASE OF BULK IN PROPORTION TO THE INCREASE OF TEMPERATURE.

Fahrenheit.		Bulk.	Fahrenheit.		Bulk.
Temp. 32	Freezing Point	1000	Temp. 75	... ...	1099
— 33	... ...	1002	— 76	Summer Heat	1101
— 34	... ..	1004	— 77	... ...	1104
— 35	... ...	1007	— 78	... ..	1106
— 36	... ...	1009	— 79	... ...	1108
— 37	... ...	1012	— 80	... ...	1110
— 38	... ...	1015	— 81	... ..	1112
— 39	... ...	1018	— 82	... ...	1114
— 40	... ...	1021	— 83	... ...	1116
— 41	... ...	1023	— 84	... ...	1118
— 42	... ...	1025	— 85	... ...	1121
— 43	... ..	1027	— 86	... ...	1123
— 44	... ..	1030	— 87	... ...	1125
— 45	... ...	1032	— 88	... ...	1128
— 46	... ...	1034	— 89	... ...	1130
— 47	... ...	1036	— 90	... ...	1132
— 48	... ...	1038	— 91	... ...	1134
— 49	... ...	1040	— 92	... ...	1136
— 50	... ...	1043	— 93	... ...	1138
— 51	... ...	1045	— 94	... ...	1140
— 52	... ..	1047	— 95	... ...	1142
— 53	... ...	1050	— 96	Blood Heat	1144
— 54	... ...	1052	— 97	... ...	1146
— 55	... ...	1055	— 98	... ...	1148
— 56	Temperate	1057	— 99	... ...	1150
— 57	... ...	1059	— 100	... ...	1152
— 58	... ...	1062	— 110	Fever Heat 112	1173
— 59	... ...	1064	— 120	... ...	1194
— 60	... ...	1066	— 130	... ...	1215
— 61	... ...	1069	— 140	... ...	1235
— 62	... ...	1071	— 150	... ...	1255
— 63	... ...	1073	— 160	... ...	1275
— 64	... ...	1075	— 170	Spirits Boil 176	1295
— 65	... ...	1077	— 180	... ...	1315
— 66	... ...	1080	— 190	... ...	1334
— 67	... ...	1082	— 200	... ...	1364
— 68	... ..	1084	— 210	... ...	1372
— 69	... ...	1087	— 212	Water Boils	1375
— 70	... ...	1089	— 302	... ...	1558
— 71	... ...	1091	— 392	... ...	1739
— 72	... ...	1093	— 482	... ...	1919
— 73	... ...	1095	— 572	... ...	2098
— 74	... ...	1097	— 680	... ...	2312

STRENGTH OF
IRON BARS AND BOILER PLATES.

THE table which follows on page 352, is the result of a series of tests conducted by Messrs. ROBERT NAPIER AND SONS, of Glasgow. As these results differ from others given in this work, we feel called upon to say that the tests seem to have been conducted with great care, and were all made with loads applied gradually. According to these tests, Staffordshire bars were very nearly equal to those from Yorkshire. Yorkshire Boiler Plates vary from the strongest, lengthwise, 56,005, to the weakest, crosswise, 46,221. These figures would represent the tenacity, or the resisting power of a boiler, supposing that the plates were *welded* together; but as this is not practicable, one-half, or thereabouts, of the resisting power is *cut away* by the formation of rivet-holes. The strength of the boiler is thus at once reduced to 23,110, or *half* the strength of the plate; and this, too, on the supposition that the rivet-holes in the plates are bored. In the case supposed, this rule would apply; but in the ordinary way of boiler-making, the rivet-holes are not bored, but *punched* out of the solid cold metal by powerful machinery. This *punching* to a great extent *impairs the tenacity of the remaining portion of the plate betwixt the holes.* Then follows another process more injurious than the former—what is technically called "drifting." This "drifting" is a process whereby the holes of one plate are made to correspond with the holes of another plate, when the plates are in

progress of being riveted together. When the holes do not exactly meet each other, so that the rivet will pass easily through both, the boiler-maker uses an instrument called a "drift." This is a taper "mandril," which is driven into the two holes, and widens them out by the force of blows with the hammer. It often happens that the metal betwixt the holes at the edge of a plate is "cracked" with the "drifting"; in many cases weakening, and in others so far destroying, the tenacity of the remaining metal, that the strength of the remaining portion cannot be taken at more than 20,000lbs. In some instances where the plate in its process of manufacturing has had little cut from its edges, when being "squared up," the edges of the plate are quite brittle; and then, what with the before-mentioned mode of punching, and what with bending the plate in a cold state, such plate may be frequently seen "cracked" from hole to hole. From these and similar causes, a boiler is often more than half destroyed before it leaves the boiler-maker's yard.

In the process of bending Boiler Plates cold, the fibres of the metal are stretched, and their tenacity impaired or destroyed. Were they passed between bending-rollers when heated to a proper working heat, the fibre would be properly drawn out, and its tenacity preserved—the same as in any other process of forging or shaping wrought iron. There cannot be a doubt that in the case of boiler-flues bent cold to diameters varying from two feet to three feet, the plates are thereby weakened to a great extent. So long as the present mode of boiler making is pursued, we shall have weak and defective boilers. The expense of heating the plates, for the purpose of bending them without injury, would be trifling. And there would

be another resulting advantage: if there were any "flaws" in the metal, these would sooner shew in the plate when in a heated state, than when bended in a cold state.

The suggestion has often been thrown out, that were the rivet-holes of Boiler Plates bored, intead of being punched, one part of the evil above pointed out would be remedied. There is no doubt but that process would be a great improvement upon the present practice; and if some independent firm would make boilers with the same care and attention to material and workmanship as they do in Steam Engine construction, they would command a trade, although their prices would necessarily be higher than those who "make" in the ordinary manner. To the user, boilers thus carefully built would be much cheaper in the end, to say nothing of the reduction to risk of life, the loss of which cannot be compensated for; and this to the humane is a consideration of importance.

The rule laid down for the strength of Steam Boilers, taking the tenacity of the plates at 60,000, is, according to the tests of the Messrs. NAPIER, far too high; and considering the before-mentioned methods of boiler making, we ought not to calculate the resisting power of boilers at more than two-thirds the amount we have been in the habit of calculating. That is, instead of calculating the tenacity at 30,000lbs, we should not calculate that tenacity at more than 20,000lbs. Thus, the bursting pressure of a tube 30 inches diameter, made of ⅜ inch plates, under the old rule would be 750lbs to the square inch; according to the new scale it would only be 500lbs to the square inch. This new rule will be much nearer to the truth in practice than the former rule; and the tube would

require to be of good material, and well made, to resist 500lbs to the square inch.

Whatever may be the strength of Boiler Plates before they are worked into shape, if care and attention are not paid to the bending, punching, drifting, and riveting, the best iron will become almost valueless. With the best material, the strength of a boiler must greatly depend upon the manner in which it is made, and the care used in its construction, even if its form be correct in principle.

In connection with this branch of the subject, the strength and power of resistance of steam boilers, we give the following extracts from a paper read before the British Association, at the Leeds Meeting in 1858, and printed in the *Mechanics' Magazine* :—

"At the late meeting of the British Association, Mr. Joseph Hopkinson, author of the work on 'The *Indicator*,' published by Weale, read a paper on Steam Boiler Explosions. The object of his paper was to shew the necessity of increased attention to the form and construction of steam boilers. After noticing the Haystack, Waggon, Cornish, and Butterley Boilers, he came to the Double Flue or Double Fire-Box Boiler, and spoke as follows :—

"'This description of steam boiler is now almost universally adopted, and, as we have had bitter experience of its repeated failures, it is surprising it has not been condemned long before now. It is strange that, although there have been so many explosions from collapse of flues at various pressures, both great and small, this form of boiler should be relied upon for its resisting powers. I speak within bounds when I state that with this form of boiler there have been more explosions than with the aggregate of all other forms. This is easily accounted for, because many imagine its power of resistance to be almost infinite. Such an idea cannot be too soon dispelled.

"'The double fire-box, or flue boiler, is formed of three tubes—two lesser and one larger. The two lesser are placed within the larger, and all are bound together by end flat plates. The space around these tubes and between them and the outer shell, constitutes the water space and the steam chamber. The pressure, whatever it is, that the steam exerts

within the boiler, is exerted *within* this space—that pressure being *internal* to the large or outer shell, and *external* to the smaller inner tubes or flues. That pressure also, whatever it may be, is exerted upon the flat ends of the boiler. This form of construction, which is the prevailing and favourite form, is not only not safe, but positively and of necessity unsafe; and it follows as a matter of course, that, with the high pressures now worked at, this want of safety becomes in many cases absolute danger; while with all boilers of this construction, and at whatever pressures they may be worked, if that pressure be appreciable, their giving way is but a question of time. The great source of danger in this form of boiler is the inner tube or flue, and the flat ends. When pressure is exerted within a tube or cylinder, with spherical ends, the tube can only give way by the metal being torn asunder; and the tendency of the strain is to cause the tube to assume the true cylindrical figure, or spherical form—the form of greatest resistance. With pressure exerted on the *outside* of a tube, the tendency of that pressure is to crush in the tube—to flatten it.

"'It is a well-known fact, that iron of any strength, when formed into a tube, will bear a much greater strain to tear it asunder if that pressure be applied *internally*, than it will bear without crushing in, when applied *externally*. A bar of iron when used as a tie-rod, will resist a very large amount of tearing force; but that same bar placed as a prop only under the weight exerted in the former case, would be doubled up, and crushed out of form. The inner tube of a boiler of this construction is but a series of props placed to sustain the immense weight of the pressure exerted externally to its diameter. The constant and never-ceasing tendency is for those props to give way—for the cylindrical tube to depart from the form of greatest resistance—to become flattened or bulged; and its ultimate crushing-in is, in the best of cases, only a question of time.

"'The double fire-box boiler was invented in America by Oliver Evans, and was for a considerable period, and in some parts is still, known as Oliver Evans' boiler. It was used in America so far back as 1786. Boiler explosions have been by no means uncommon in America, as is well known; indeed, so numerous have they been, and attended with such dire results, that in 1817, a searching enquiry into their cause, with a view to their prevention, was instituted under the sanction of the American Government. In reference to the fire-box boiler, the report presented after that investigation states, "Many respectable Mechanics and Engineers in this country considered that the improved boiler invented by Oliver Evans obviated the objections to High-pressure

Engines. The late melancholy occurrence on board the *Etna* in the waters of the New York harbour, is evidence that they have been deceived." Mr. JACOB PERKINS, in his report on the same form of construction, says, "This form of boiler should certainly be abandoned." Another eminent Engineer, Mr. C. J. JARVIS, wrote as follows :—"A flue of this kind may be placed in such circumstances, that when the steam and temperature get unusually high, it suffers a minute change of form. Under these circumstances it will inevitably collapse sooner or later, according to the extent to which its form is altered at each time it is unusually heated, and the frequency of that occurrence, let it be surrounded with as much water as it may."

"'There is no doubt that providing the flues were strictly cylindrical, their strength would be immeasurably great; but such is not the case, nor is it possible to make them strictly true. The very weight of the material itself is sufficient to destroy the true figure of the flue, even providing it were made of one whole plate without rivets or lap joints; but in the ordinary flue, as used in all boilers, the figure of greatest resistance is gone at once, by the overlapping of the plates. In the case of horizontal tubes, as employed in steam boilers, the pressure is not uniform; for, while the pressure on the top part of a flue, three feet diameter, may be 20lbs per square inch, the pressure upon the under side would be 1½lbs more; because the weight of the column of water has to be added to the pressure on the lower part of the tube. The cylindrical figure in that case is not the true figure of greatest resistance; and it is not likely that in the ordinary business of boiler making, much care can or will be bestowed in calculating, or afterwards in the making of the tube, agreeable to the true figure of greatest resistance. We therefore need not be surprised at the explosions which occur from collapse of flues. The very form almost seems to invite the occurrence. It is by a continued working of such description of boiler, and the always increasing weakness of the flue, from its varied pressure and temperatures, and its consequent change of form, that ultimately explosions occur. Hence the reason why a tube that has been proved to a pressure of 80lbs to 100lbs to the square inch may afterwards fail under a pressure of less than half that amount.

"'There are other changes in connection with this form of boiler which cannot easily be prevented from taking place. Plates have cracked and given way on the under side of the boiler, from the contraction and expansion caused by the difference of temperature of the top and bottom side of the boiler. A boiler is materially hastened in its destruction by the emptying of it while hot, and then suddenly cooling it by admitting

cold water, to get off the scale. Double fire-box boilers have been fractured on the under side, both in the line of rivets, and even across the plates, from this cause. Look again, when starting a boiler and getting up the steam, and notice the length of time the water on the under side of the flue is before it is even lukewarm. Here, also, is an important action taking place in reference to the safety of the boilers.

"'The flat ends of this form of boiler are also a source of weakness. The reason of this will be at once apparent. The tendency of the force within the boiler is to cause the flat end to bulge outwards—to assume, in fact, the spherical form. This brings unusual and unequal strain upon the rivets which join the plates together. These at last give way, being either torn out, or the plate itself riven asunder across the line of rivets, and then out the ends go. Instances of this kind can be seen in almost every explosion. In some cases the plates have been torn asunder as though they were but paper. When once any part of a boiler gives way the other parts become exposed to unequal strain from the expanding contents, which exercise a tearing and impelling force equal to that of gunpowder. To counteract this tendency of the flat end bulging outwards, it is usual to stay them. Stays, at best, are but inferior substitutes for the form of greatest resistance. Stays would be of no service applied in a sphere subjected to internal pressure; the power of resistance would be exactly that of the metal to sustain the strain, exerted upon all parts alike. Stays would be of no advantage unless they could be applied so as to strengthen that metal in all its parts; and this, as will be seen at once, could only be accomplished by using metal of greater thickness or strength for the original construction. Boiler stays, therefore, are at all times but an insecure substitute for real strength of construction. And the manner in which they are almost invariably applied, renders them still more insecure, and at times positively dangerous, because they incite to the idea of security where it is in reality absent. To counteract the tendency of flat ends bulging outwards, or being blown off by the internal pressure, it will be at once apparent that, if we desired to secure the utmost benefit the stay-rod is capable of rendering, we should let it proceed through the end of the boiler in a direct line with its own length, and then, by means of washers, screws, and nuts, secure it in that place. The strain would then be direct to its own length, and its power of resistance would be equal to the weight applied perpendicularly, which the rod would sustain without breaking asunder, But stays are seldom thus applied. Instead of proceeding through the boiler ends, the stay-rods are bent at right angles, and riveted to the boiler through the bent parts. The strain, as will at once be seen, is mainly on the bent portions—to

straighten them out—instead of the pull being in a direct line to the stay-rod, as would be the case if applied as before described. When we apply tie-rods to a floor or a roof, or to a beam of any kind, we do not copy the mode of application adopted with steam boiler tie-rods. We apply them so as to receive the full power of resistance against strain or weight; and we ought also to do so in the case of steam boilers. The principle of application appertaining to the gusset-stay is precisely that just described. It is formed of angle iron, and a gusset of Boiler Plate. The strain in the case of the gusset-stay is on the angles of the angle iron, and the rivets by which these are attached to the ends and side of the boiler. The power of resistance is just what these angle irons and rivets will bear without breaking, straightening, or tearing out. It is not by any means the amount which the same metal differently applied would give.'"

TABLE.

STRENGTH OF WROUGHT-IRON BARS,

BY MESSRS. ROBERT NAPIER AND SONS.

IRON BARS.

	Tenacity in lbs per sq. inch.
Yorkshire: strongest	62886
" weakest	60075
" (forged)	66392
Staffordshire: strongest	62231
" weakest	56715
West of Scotland: strongest	64795
" weakest	56655
Sweden: strongest	48232
" weakest	47855
Russia: strongest	56805
" weakest	49564

IRON PLATES.

Yorkshire: strongest lengthwise	56005
" weakest lengthwise	52000
" strongest crosswise	50515
" weakest crosswise	46221

Note—The strongest lengthwise is the weakest crosswise, and *vice versa*.

STEEL BARS.

		Tenacity in lbs per sq. inch.
Steel for tools, rivets, &c. :	strongest	132909
"	weakest	101151
Steel for other purposes :	strongest	92015
"	weakest	71486

STEEL PLATES.

Strongest lengthwise	94289
Weakest lengthwise	75594
Strongest crosswise	96308
Weakest crosswise	69016

Note—The strongest and weakest lengthwise are also respectively the strongest and weakest crosswise.

The utility of testing bars, beams, and boilers to an extreme, or considerably more than the weight or strain required in actual use, is questioned by many; and so far as practice has taught us, it is better not to test either beams, bars, or boilers to more than the ordinary strain required. We may, by an extreme test, prove that the article tested withstood such and such a strain; but at the same time we do not know how such test may have injured the substance tested. For instance, take the testing of a cast-iron beam at Messrs. MILBURNS' Iron Foundry, Staleybridge. The beam was 27 feet long. A weight of 24 tons was hung on the centre, with which the beam deflected $1\frac{1}{8}$ inches. When the weight was removed the beam assumed its former form, and the parties present considered that the test had not injured the beam, inasmuch as the beam had returned to its original position. The same beam was shortly afterwards tested with 16 tons hung on the centre, when it broke, though there were eight tons less than it had withstood before.

Take another instance—that of the testing of a steam boiler at Messrs. HARGREAVES, at Accrington. The boiler was under the inspection of the Manchester Boiler Association. The boiler referred to was recommended to be tested, and the hydraulic test was resorted to. The extreme working-pressure of the boiler was a little under 40lbs to the square inch, and the test the boiler was submitted to was 70lbs to the square inch. To all appearances, under the test the boiler was safe at that pressure. In about three months after this testing, the boiler exploded; and, from our own investigation, we were convinced that the test to which the boiler had been subjected, injured the structure; and from that time till the whole gave way, the boiler had been gradually getting weaker. The flues had been strained by the test—the pressure being on the outside of the diameter. When once the form of a flue in a boiler begins to change, that change goes on in an accelerated ratio, until the flue becomes too weak to resist the ordinary working-pressure.

There can be no doubt that the testing of any structure or machine to the full strain the apparatus may be expected to resist, is highly necessary; but beyond *that*, there is more risk of injury to the apparatus tested, than any chance of good resulting from an extreme test.

The word "test" carries with it to the theorist and the casual observer an idea of security; because such "test" affords proof that the machine, or structure, has withstood a certain force. This may be quite true; but it does not follow that the same machine or structure will resist the same amount of force again, or anything approximating to it.

RULE FOR CALCULATING THE STRENGTH OF CYLINDERS, OR BOILERS, AS GENERALLY APPLIED.*

The tenacity of the metal of which a boiler is constructed, is about 60,000lbs, or six-sevenths that of good wrought iron—a bar one inch square being the standard.

As, however, the cylinder which constitutes the boiler is not whole, or *in one piece* welded together, but is composed of a number of plates riveted together —the plates also being cut away for the holes—it will be necessary to diminish the number which expresses the tenacity. Let, therefore, the tenacity be put at 30,000lbs in place of 60,000lbs.

Multiply the numerator of the thickness by the tenacity of the metal; and multiply the denominator by half the diameter of the cylinder in inches, then divide the numerator by the denominator, and the quotient will give the strength of the cylinder, or bursting-pressure.

EXAMPLE I.

Take a cylinder 30 inches diameter made of $\frac{3}{8}$ plate: thus—

$$\frac{3}{8} \times \frac{30{,}000}{15} = \frac{90{,}000}{120} \text{ then } 90{,}000 \div 120 = 750\text{lbs the bursting-pressure.}$$

EXAMPLE II.

A cylinder of six feet diameter, made of $\frac{1}{2}$-inch plate: thus—

6 feet = 72 inches

$$\frac{1}{2} \times \frac{30{,}000}{36} = \frac{30{,}000}{72} \text{ then } 30{,}000 \div 72 = 416\tfrac{17}{18}\text{lbs bursting-pressure.}$$

* This rule is the one generally acted upon, and is no doubt pretty nearly correct, when the metal is without flaws, and the workmanship without defects. But as these cannot always be relied upon, the rule and the deduction from it will be found to be far too high for ordinarily made boilers.

THE SAFETY VALVE.

THE form and construction of this indispensable adjunct to the steam boiler are of the highest importance, not only for the preservation of life and property, which would, in the absence of that means of "safety," be constantly jeopardised, but also to secure the durability of the steam boiler itself. And yet, from the manner in which many Safety Valves have been constructed of late years, it would appear that the true principle by which *safety* is sought to be secured by this most valuable adjunct, is either not well understood, or that it is disregarded by many Engineers and boiler-makers. Many of those unfortunate calamities—boiler explosions—have occurred when, to all appearance, the Safety Valves attached have been in good working order: and Juries under the presidency of Coroners, have not unfrequently been puzzled, and sometimes guided to erroneous verdicts, by scientific evidence adduced before them, tending to shew that nothing was wrong with the Safety Valves; and that the devastating catastrophes could not have resulted from over-pressure, because in such case the Safety Valves would have prevented them.

If the inventor of that most useful and scientific apparatus, the Safety Valve, could but witness some of the forms given to the instrument, and some of the modes of construction adopted, he would indeed marvel to see the degeneracy which, in this day of general improvement, is but too often apparent in the

manufacture and construction of this essential and indispensable adjunct.

The portions numbered 1 and 2 on figure 91, represent variations of the Common, or Mushroom, Valve. This is usually constructed with a guide-pin, to pass through a hole or socket provided in the cross-bar inserted in the seating of the Valve—such guide-pin and steadying-socket being *underneath* the Valve, and consequently *within* the boiler, constantly and fully exposed to the action of the steam, the varying temperatures, and to the accumulations of dirt and other extraneous matters. From this form of construction alone, numerous boiler explosions have occurred—from the stem, or guide-rod, of the Valve having either got bent or otherwise damaged; from its having become corroded in the steadying-socket of the cross-bar, or from its becoming fast in its place, when closed, from many other and obvious causes. It is clear that when the Mushroom Valve is in any one of these states, it is impossible for it to act, and the boiler is, to all intents and purposes, as if nothing in the shape of a Safety Valve had been provided.

Another objection to this form of Safety Valve is, that the weight to keep down the Valve till the limit of safety is approached, is applied in the worst form possible to ensure accuracy in the indications of the Valve, or to allow of the free working of that Valve when over-pressure requires it to open. In Valves of this construction, there is generally provided on the lever a swell, or projection, rounded down at the end to a dull point; and this dull point rests in a small counter-sunk hole in the outer tip, or central projection of the Valve (as in the portion numbered 2 of figure 91); or the point on the tip of the Valve rests

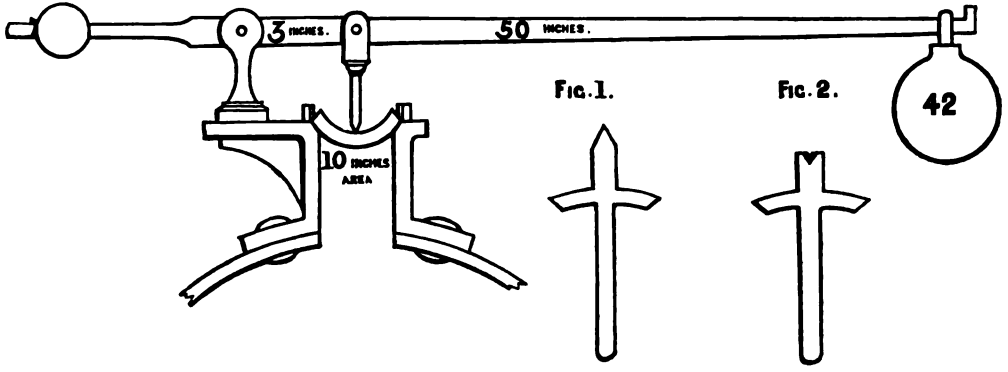
in the counter-sunk hole in the projecting portion of the lever (as the portion of figure 91 numbered 1). When the weight is hung on the other end of the lever, or at such place upon it as has been arranged for, the swell, or projection, on the lever bears upon the tip of the Valve, and keeps that Valve down on its seat until it is raised therefrom by over-pressure of steam within the boiler. But it is a question arising from this mode of applying the weight, whether the Valve *can* act at the time and in the manner designed. In the first place, the joint at the end of the lever, where it is attached, must necessarily have some play given it. Oftentimes greatly too much is given; or rather, no care to have exactness of fitting is exercised. This play, from the action of the lever, by wear and tear, becomes greater and greater; and every departure from exactness, either in the original manufacture, or from subsequent wear, takes the weight from the *centre* of the Valve, and brings it more upon one or other of its sides than the rest. These deviations from exactness may be small, almost infinitesimal, in themselves: but multiplied as they are in fact, in the ratio of the length of the lever from its attachment to the point of bearing on the Valve, they become anything but inappreciable, or non-detrimental to the free action of the Valve. When the Valve is thus weighted out of its centre, two separate but injurious actions take place: first, when over-pressure occurs, instead of the Valve being lifted bodily from its seat, it becomes tilted, and the steam escapes at *one side* only: and, second, in consequence of this tilting, the guide-rod often becomes bound fast in the guiding-socket of the cross-bar; and the Valve is thus prevented from acting, except in a very limited

degree—not nearly sufficient in cases of over-pressure. The worst is, that under the circumstances supposed, the higher the pressure—that is, the greater the danger from which the Valve is required to relieve—the less capable does it become of acting in the manner for which it was calculated and designed: for the greater the force brought to bear upon the tilted portion of the Valve—(and be it remembered that this tilting exposes more of the surface of the Valve-face on the tilted side than on the side which still remains covered by the seating)—the more firmly does the Valve become bound in the guiding-socket. From these and other causes of a similar nature, Safety Valves of this construction cannot be made to work accurately—and they are totally inapplicable for high pressures, if "safety" is to be a consideration. The indications, however carefully the Valves may have been weighted, are often most inaccurate. The author has known Valves of this description to be kept as perfectly down to their seatings as they are capable of being kept—that is, without any escape of steam from over-pressure—when the pressure in the boiler, as measured by a more accurate test, has been 12lbs more than the Valve was calculated and weighted to blow off at. With a Valve of this description, any one, by moving the lever to and fro, may cause the steam to escape at either of its sides. To counteract this tendency to tilt, other guides have at times been applied; but it has been found in practice, that this attempt to remedy one evil has only been to create others, which equally tended, and in like manner, to prevent the proper and safe working of the Valve.

The main portion of figure 91 is a representation of a Safety Valve which has been designed and

LEVER SAFETY VALVE.

FIGURE 91.



introduced to prove that a Valve of the ordinary kind, may be made to act well, generally speaking—to blow off from over-pressure, with far greater accuracy than either of the constructions before considered, and also with a uniform discharge of steam from all sides of the Valve orifice, when open. The Valve is of the spherical form on its under side; and it is placed within outward guides affixed to the seating. The weight is brought upon the Valve from a low-fixed centre—the centre-pin being jointed to the lever, or fixed thereon by other means, so that there be the requisite play for the pin always to bear on the centre of the Spherical Valve. The small weight on the short, or fastening, end of the lever, is merely for the purpose of balancing the long end of the lever, so that when the ball-weight for weighting the Valve is off, the Valve is entirely free from outward pressure. Where this portion of the arrangement is dispensed with, the weight of the lever as it bears on the Valve has to be taken into account, when calculating the weight to be used for weighting the Valve, and also the several distances on the lever at which that weight will have to be placed for the various pressures required.

In all cases it is advisable to have the face of the seating of the Safety Valve as narrow as the varying modes of construction will allow. The Spherical-faced Valve is best adapted for this and other beneficial purposes: for it is found in practice that the sharp edge of the seating, taken off only by grinding it and the Spherical Valve to a face, results in the greatest accuracy that can be obtained, while this form and mode of construction also ensures the best-fitting Valve for "bottling up" the steam when it is not required to escape.

The Valve shewn by figure 91 is not adduced and recommended as one perfect in every particular—but it is believed to be as good a Valve as can be made simply as a Lever Valve—securing the greatest accuracy of which this form of construction is capable, and providing for the discharge of steam better than any other mere Lever Valve yet introduced.

In connection with this subject of Safety Valves, the author would not be doing his duty to those for whom his work is intended, were he, from any feeling of mock-modesty, to refrain from describing the construction and the advantages of what is now very well known as "HOPKINSON'S (PATENT) COMPOUND SAFETY VALVE"—as that Valve possesses important features not to be found in connection with any other Valve; and as it provides against that prolific source of boiler explosions resulting from deficiency of water, as well as for the copious discharge of steam at over-pressure, under the ordinary conditions of working. When the facts are stated, that this Compound Valve has been applied to upwards of three thousand boilers—and that in no single instance has a boiler with this Valve attached, exploded or suffered injury, either from over-pressure or deficiency of water—while most numerous are the instances where boilers have been *saved* by the simple but certain action of the instrument, under circumstances which, with the ordinary Valve, would inevitably have resulted in explosion, the author feels that he may fairly claim to be exempt from the charge of "puffing his own wares" in giving the following description of a construction which has already effected much good, and which, as experience warrants him in saying, is the most effective *Safety* Valve ever yet introduced into Steam Engineering.

ıe description of the Compound Valve which ws formed part of the paper read before the ish Association, at the Leeds Meeting in 1858, ı which extracts have already been given on pages to 352: the paper, as a whole, appeared in the *hanics' Magazine*, in its report of the proceedings ıe Association on the occasion named:—

ıe (Patent) Compound Safety Valve comprises two distinct valves; 5½-inch diameter valve, with flat face, and a spherical or ball-valve, 3 inches diameter. The smaller, or ball-valve seats upon an g in the centre of the larger Valve. The larger valve is weighted ans of a lever and ball, as in the common Safety Valve. There is a bridge, or cover casting, which fits to the large valve, and forms atre for the centre-pin to give pressure upon the valve enclosed the casing. Resting upon the holed-centre of the large valve is ll-valve. This last is weighted by a dead weight inside the boiler dead weight being composed of iron-plate castings. When the exceeds the pressure this ball-valve is weighted to, the valve lifts, ıe steam escapes through the openings in the bridge casting into me, or shell-casing, and out into the atmosphere. As soon as the alve lifts from *its* seat, the large flat-valve also lifts from *its* seat: *double means of discharge* is given to the excess of steam. This e is of importance, inasmuch as the whole construction forms a possessing an opening, or discharging area, equal to an ordinary y Valve 8½ inches diameter.

The Compound Valve cannot be weighted beyond its working-pres- whilst the boiler is at work. Should an attempt be made to over- ht the outside lever, or even should a man press upon it with all his , it would be useless: so long as the ball-valve is there, properly hted inside the boiler, all is right. Should the ball-valve be over- hted intentionally, whilst the boiler is standing for cleaning, it may ntly be detected on getting-up the steam.

Turning to the next feature, we come to [illegible] ed arrangement eficiency of water. There is a lever [illegible] boiler. The which bears the dead weight for the [illegible] through a hole in this suspended lever. On this [illegible] lar, arranged to allow the lugs of [illegible] to come in [illegible] One end e lever, or beam, [illegible] in the boiler [illegible] float; and

at the opposite end there is a balance weight, to counteract the buoyancy of the float when immersed in the water. The smaller weight is also to keep the tip of the lever up against the underside of the top of the boiler. The float on the other end, or long arm of the lever, is immersed in the water to such a depth as is fixed for extreme "low-water mark." Should the water begin to leave the float, the specific gravity of the float will be brought upon the long end of the lever. This lever, it will be remembered, is hung to the boiler, and works on a centre. By the depression of the long end, the lugs of the short end are brought into contact with the collar on the rod attached to the central, or spherical-valve, and that valve is thereby raised from its seat. Should the water still get lower, the valve continues to rise, and will continue raised until the water be again at it proper height. Should the first warning be disregarded, the steam will be discharged from the boiler, stopping all working, and rendering explosion impossible. Timely notice is given of such first deficiency by the continual quivering of the valve on its seat; and if this be not attended to, the valve will open to the full extent.

"The advantages of the Compound Valve are as follow:—Its combination of parts are such as to act for excessive pressure and deficiency of water; its general mechanical and practical arrangement—the Valve possessing neither spindles, guides, rubbing surfaces, nor parts liable to adhere; it is simple in construction and certain in action; while it can be used as any other Valve for general working. It prevents the careless, the ignorant, or the wanton from causing either injury to the boiler, or boiler explosions; it is not liable to derangement, and is in every detail what a Safety Valve ought to be."

To this the author has only to add that he believes the Compound Valve, constructed as above described, has not hitherto been exceeded for accuracy, if indeed it has been reached. It is so sensitive in action that when the steam is of that pressure as to just affect the Valve on its seat, should the Engine be then started, the revolutions of the Engine may be observed and counted by merely noticing the pulsations of the Valve—as it will rise and fall according to the minute variations of pressure occasioned by the withdrawals and stoppages of steam from the boiler to impel the piston.

RULE:

TO ASCERTAIN AT WHAT PRESSURE A SAFETY VALVE IS WEIGHTED.

First, ascertain the length in inches of the fulcrum, and the length in inches of the lever, from its attachment to the place where the weight is hung. Then ascertain the weight, in pounds, of the ball-weight.

RULE.

Multiply the length of lever by the weight of the ball-weight. Then multiply the area of the Valve* by the distance of the fulcrum from the attached end of the lever. Then take the product of the former, and divide by the latter. The quotient is the pressure for which the Valve is weighted, in pounds per square inch.

EXAMPLE.

42 lbs weight of ball.	10 inches, area of Valve.
50 inches, length of lever.	3 „ length of fulcrum.
2100	30

30) 2100 (70lbs per square inch.
210·

This illustration is from the Valve shewn by figure 91, which has the respective measurements and weights figured thereon.

The introduction of the above simple method of calculation is not for the purpose of superseding any readier method, or those usually adopted by the mathematician, or by the skilled and practical Engineer. It is intended for those who have not any other means of arriving at the required result.

* The area of any Valve may be found on reference to the "Table for Safety Valves, Cylinders, Air Pumps, &c.," in the Appendix.

FINAL HINTS REGARDING THE INDICATING OF STEAM ENGINES.

THE reader who has thoughtfully perused the foregoing pages, and attentively practised the simple and plainly-expressed instructions therein contained, will have become thoroughly acquainted with the principle of the Steam Engine *Indicator*, and the several modes of applying it to practical use. It only, therefore, now remains for us, in concluding the work, to give a final hint on one or two points affecting the indications taken by the instrument, to prevent parties using it from arriving at erroneous conclusions.

First, then, in indicating for the purpose of ascertaining the *available* power of an Engine—that portion of the whole power exerted which is applicable to the turning of machinery, or for any other work the Engine is set to perform—it is indispensable that the amount, or portion, of that total power exerted by the steam which is expended in overcoming the inertia and friction of the Engine and shafting, should be ascertained. This is accomplished by taking a diagram while the Engine and shafting *alone* are running; and then, by ascertaining the average pressure per square inch of the steam upon the piston, the amount of power required to run the Engine and shafting is obtained.

Second—take another diagram when the Engine is fully loaded: that is, when it is performing the *whole*

of the work it is expected or set to perform. Of course, it will be apparent that this second diagram should be taken with the steam at the same pressure in the boiler it was at when the first, or friction, diagram was taken. This second diagram, when calculated in the usual manner, will give *the total* amount of power the steam is exerting. Deduct from that total amount the portion shewn by the first diagram to be expended in overcoming the inertia and friction of the Engine and shafting, and the remainder is the amount of AVAILABLE POWER obtained from the Engine. By ascertaining the amount of fuel consumed per hour, and apportioning this to the *available* power exerted per hour, the amount of profitable, or productive, *duty* performed, in contrast with the expenditure of fuel, will be ascertained.

The foregoing is the only reliable mode by which the AVAILABLE POWER exerted by any Engine can be ascertained with any degree of accuracy. It will not answer to take alone the total amount of power exerted. To overcome the inertia and friction of the Engine and shafting, requires considerably more power in some cases than others. Indeed, the variations on this point are constant and often great. The power required to run the Engine and shafting must, therefore, in all cases be deducted from the amount of total power exerted, or the conclusion as to the AVAILABLE POWER of the Engine will be erroneous.

For instance, we know of a case where a 60-horse Engine was compounded, by the addition of two high-pressure cylinders. The result was, that when the Engine was indicated with the full load on, the indications shewed a great increase in the indicated horse-power—and this, although the work the Engine

was performing was precisely the same as before the Engine was compounded. To shew that a saving of fuel had resulted from that compounding, the fuel expended was apportioned to *the total power* exerted by the Engine both before and after the compounding. That is to say, the calculation was made from the diagrams which included the power required in each case to drive the Engine and shafting. The result of this most incorrect mode of calculation was to shew that the Compounded Engine consumed a less amount of fuel per horse power, than the same Engine did before compounding was resorted to: whereas, had the calculation been—as it ought to have been—*upon* the AVAILABLE POWER only of the Engine in its two states, the reverse would have been shewn: for the great amount of additional friction and condensation consequent on the employment of two extra cylinders would have been found to have absorbed all the advantage, and probably more than was obtained from an increase of steam-pressure in the boiler. There are other modes of compounding, as the reader will be aware: but *the value* of any and every mode can be tested in the manner just explained. It cannot, however, be too strongly inculcated, that the only correct or reliable *test* is that which applies *only* to the AVAILABLE POWER both before and after compounding.

In all cases when diagrams for the purposes specified above are taken,—and, indeed, for all purposes of contrast, or relative calculation,—the Engine should run each time at the same speed. If this be not observed, the result cannot be correct. Variations of speed absorb more or less of the total power exerted, in proportion to the amount of the variation:

ɔtain indications which will accurately
xact quantity either of the total power
AVAILABLE portion of that power, it is
hat the Engine run at the same speed
ent indications are taken.

APPENDIX:

CONTAINING

TABLES AND OTHER INFORMATION CALCULATED TO BE OF SERVICE TO ENGINEERS AND OTHERS ENTRUSTED WITH THE MANAGEMENT OF THE STEAM ENGINE.

APPENDIX.

A TABLE:

SHEWING THE QUANTITY OF FUEL CONSUMED IN PROPORTION TO THE PRESSURE OF STEAM, TO PRODUCE EQUAL POWER WHEN WORKED EXPANSIVELY.

Pressure of the Steam in lbs per Square Inch above the Pressure of the Atmosphere.	Length of Stroke when the Steam is cut off in Cylinder.	Average Pressure on the Piston in lbs per Square Inch.	Consumption of Fuel in lbs per Hour per Horse Power.
lbs		lbs	lbs
4		16	8
7	$\frac{2}{3}$	16	7
10	$\frac{1}{2}$	16	$6\frac{1}{4}$
15	$\frac{1}{3}$	16	$5\frac{1}{2}$
20	$\frac{1}{4}$	16	$4\frac{3}{4}$
25	$\frac{1}{5}$	16	4
30	$\frac{1}{6}$	16	$3\frac{1}{2}$

There is no practical advantage in cutting off the steam at more than $\frac{1}{6}$th to $\frac{1}{8}$th the length of the stroke; but there is gain by an increase of pressure in the boiler, provided the pipes and other heated exposed surfaces be well protected from the action of the atmosphere by a non-conducting substance. If more than $\frac{1}{8}$th be required, it will be best attained by using a small high-pressure and a large low-pressure cylinder, working them compound. The difference in the areas of the cylinders must be the same numbers as the amount of expansions required.

Where expansion is carried out with high-pressure steam, the cylinder should be well covered, or cased, and heated to a high temperature, that the steam may not be robbed of its heat and power by the great conducting property of cast-iron.

A TABLE:

SHEWING, according to the pressure used, the average pressure of steam upon the piston, cut off at any portion of the stroke, beginning at 10lbs, and advancing in 5lbs up to 150lbs per square inch; enabling the Engineer to determine at any given pressure the amount of expansion requisite for the full power to be obtained, and the saving thereby to be effected. In all cases the pressure of the atmosphere must be added to the pressure of the steam above atmosphere, when reference is made to the table for the average throughout the stroke.

Example: 15lbs pressure on the piston above atmosphere, cut off at one-fourth the piston's traverse, will be thus: 15lbs steam and 15lbs the pressure of the atmosphere=30: then look for 30lbs at the head of the table, and down the first column for $\frac{1}{4}$; trace that $\frac{1}{4}$ under 30, and you will find the average to be $17\frac{3}{4}$lbs throughout the stroke. For other proportions, follow the same principle—that is, supposing the vacuum to be 15lbs. If there be not 15lbs of a vacuum, the amount of pressure below must be deducted from the average.

If a Non-condensing Engine, where the steam is expanded into the atmosphere, the case will be different: because the steam cannot expand below 15lbs to the square inch,—that being the pressure of the atmosphere.

Example: 45lbs steam above atmosphere upon the piston of a High-pressure Engine, cut off at one-fourth the length of the stroke. The average pressure

throughout will be—allowing 1lb for friction and back-pressure to force out the steam in the cylinder—$19\frac{3}{4}$lbs. Thus: 45lbs steam cut off at one-fourth the stroke, with 15lbs added, make 60lbs. Look for 60 on the top line of the table, and $\frac{1}{4}$ on the side. Trace that $\frac{1}{4}$ to the figures under 60, and the average will be found to be $35\frac{3}{4}$lbs. Take 16lbs from $35\frac{3}{4}$lbs, for atmospheric pressure and friction, and there remains $19\frac{3}{4}$lbs—the available average pressure on the piston.

Example: 30lbs cut off at one-third. Add 15=45. The average in the table will be $31\frac{1}{2}$: deduct 16lbs, and there remain $15\frac{1}{2}$lbs, the available average pressure upon the piston.

Another Example: 15lbs cut off at half-stroke. Add 15=30. The average in the table will be $25\frac{1}{4}$. Deduct 16lbs and $9\frac{1}{4}$ remains, the average available pressure.

In these examples the steam in the cylinder has expanded to atmospheric pressure.

In proportion to the pressure of the steam, the cut-off will have to be varied, as shewn by the examples, if the steam is to be expanded to its full limit in the cylinder of a Non-condensing Engine; that is, down to 15lbs, or equal to the pressure of the atmosphere.

All steam above atmosphere at the termination of the stroke will be lost. Thus: if 45lbs steam above atmosphere be used, and expanded in the cylinder to 10lbs above atmosphere, then exhausted, 10lbs out of the 45lbs will have been lost.

VI.

A TABLE:

Shewing the average Pressure of the Steam upon the Piston throughout the Stroke, when cut off in the Cylinder from $\frac{1}{2}$ to $\frac{11}{12}$, commencing with 10lbs and advancing in 5lbs up to 150lbs Pressure.

Steam Cut off in the Cylinder.	Pressure in lbs. at the commencement of the Stroke.														
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	
	Average Pressure in lbs. upon the Piston.														
$\frac{1}{2}$	7	$10\frac{1}{2}$	$14\frac{1}{2}$	$17\frac{1}{2}$	21	$24\frac{1}{2}$	28	$31\frac{1}{2}$	35	$38\frac{1}{2}$	42	$45\frac{1}{2}$	49	$52\frac{1}{2}$	1
$\frac{3}{4}$	$9\frac{1}{4}$	14	$18\frac{3}{4}$	$23\frac{1}{4}$	$28\frac{1}{4}$	$32\frac{3}{4}$	$37\frac{1}{4}$	42	$46\frac{3}{4}$	$51\frac{1}{4}$	$56\frac{1}{4}$	61	$65\frac{1}{4}$	$70\frac{1}{4}$	2
$\frac{1}{3}$	6	9	12	15	$17\frac{1}{2}$	$20\frac{1}{2}$	$23\frac{1}{2}$	$26\frac{1}{2}$	$29\frac{1}{2}$	$32\frac{1}{2}$	$35\frac{1}{2}$	$38\frac{1}{2}$	$41\frac{1}{2}$	$44\frac{1}{2}$	3
$\frac{1}{4}$	$8\frac{1}{4}$	$12\frac{1}{2}$	17	21	$25\frac{1}{4}$	$29\frac{1}{4}$	$33\frac{1}{2}$	38	$42\frac{1}{4}$	$46\frac{1}{4}$	$50\frac{1}{2}$	55	$59\frac{1}{4}$	$63\frac{1}{4}$	4
$\frac{2}{5}$	$9\frac{1}{5}$	$14\frac{1}{5}$	$19\frac{1}{5}$	24	$28\frac{3}{5}$	$33\frac{1}{5}$	$38\frac{1}{5}$	$43\frac{1}{5}$	$48\frac{1}{5}$	53	$57\frac{3}{5}$	$62\frac{1}{5}$	$67\frac{1}{5}$	$72\frac{1}{5}$	5
$\frac{1}{6}$	$5\frac{1}{6}$	$7\frac{5}{6}$	$10\frac{1}{6}$	13	$15\frac{1}{6}$	$18\frac{1}{6}$	$20\frac{5}{6}$	$23\frac{1}{6}$	26	$28\frac{1}{6}$	$31\frac{1}{6}$	34	$36\frac{1}{6}$	39	6
$\frac{1}{7}$	$7\frac{1}{7}$	$11\frac{1}{7}$	$15\frac{1}{7}$	19	23	$26\frac{6}{7}$	$30\frac{1}{7}$	$34\frac{1}{7}$	$38\frac{1}{7}$	42	46	$49\frac{6}{7}$	$53\frac{1}{7}$	$57\frac{1}{7}$	7
$\frac{1}{8}$	9	13	18	$22\frac{1}{2}$	27	$31\frac{1}{2}$	$36\frac{1}{2}$	$40\frac{1}{2}$	$45\frac{1}{2}$	$49\frac{1}{2}$	$54\frac{1}{2}$	$58\frac{1}{2}$	$63\frac{1}{2}$	$67\frac{1}{2}$	8
$\frac{2}{9}$	$9\frac{2}{9}$	$14\frac{1}{9}$	$19\frac{1}{9}$	$23\frac{2}{9}$	$29\frac{1}{9}$	$34\frac{1}{9}$	39	44	49	$53\frac{2}{9}$	$58\frac{1}{9}$	$63\frac{1}{9}$	$68\frac{1}{9}$	$73\frac{2}{9}$	9
$\frac{1}{10}$	$4\frac{1}{2}$	7	$9\frac{1}{2}$	$11\frac{1}{2}$	14	$16\frac{1}{2}$	$18\frac{1}{2}$	$20\frac{1}{2}$	$23\frac{1}{2}$	$25\frac{1}{2}$	$27\frac{1}{2}$	$30\frac{1}{2}$	$32\frac{1}{2}$	$34\frac{1}{2}$	10
$\frac{1}{11}$	$9\frac{2}{11}$	$14\frac{3}{11}$	$19\frac{3}{11}$	$24\frac{1}{11}$	$29\frac{1}{11}$	$34\frac{1}{11}$	$39\frac{1}{11}$	$44\frac{1}{11}$	$49\frac{1}{11}$	54	59	64	69	$73\frac{2}{11}$	11
$\frac{1}{7}$	$4\frac{1}{7}$	$6\frac{1}{7}$	$8\frac{1}{7}$	$10\frac{1}{7}$	$12\frac{1}{7}$	$14\frac{3}{7}$	$16\frac{3}{7}$	$18\frac{3}{7}$	21	$23\frac{1}{7}$	$25\frac{1}{7}$	$27\frac{1}{7}$	$29\frac{1}{7}$	$31\frac{1}{7}$	12
$\frac{3}{8}$	$6\frac{1}{8}$	$9\frac{1}{8}$	$12\frac{3}{8}$	16	$19\frac{1}{8}$	$22\frac{1}{8}$	$25\frac{3}{8}$	$28\frac{3}{8}$	32	$35\frac{1}{8}$	$38\frac{1}{8}$	$41\frac{3}{8}$	45	$48\frac{1}{8}$	13
$\frac{3}{9}$	$7\frac{3}{9}$	$11\frac{2}{9}$	$15\frac{2}{9}$	$19\frac{2}{9}$	$23\frac{2}{9}$	$27\frac{2}{9}$	$31\frac{1}{9}$	$35\frac{1}{9}$	$39\frac{1}{9}$	$43\frac{1}{9}$	$47\frac{1}{9}$	$51\frac{1}{9}$	$55\frac{1}{9}$	$59\frac{1}{9}$	14
$\frac{4}{9}$	$8\frac{4}{9}$	$13\frac{1}{9}$	$17\frac{2}{9}$	$22\frac{1}{9}$	$26\frac{2}{9}$	$31\frac{1}{9}$	$35\frac{1}{9}$	40	$44\frac{1}{9}$	49	$53\frac{1}{9}$	$57\frac{2}{9}$	$62\frac{1}{9}$	$66\frac{2}{9}$	15
$\frac{5}{9}$	$9\frac{1}{9}$	$14\frac{1}{9}$	19	$23\frac{4}{9}$	$28\frac{1}{9}$	$33\frac{1}{9}$	$38\frac{1}{9}$	$42\frac{7}{9}$	$47\frac{2}{9}$	$52\frac{1}{9}$	$57\frac{1}{9}$	62	$66\frac{4}{9}$	$71\frac{1}{9}$	16
$\frac{6}{9}$	$9\frac{3}{9}$	$14\frac{3}{9}$	$19\frac{3}{9}$	$24\frac{3}{9}$	$29\frac{1}{9}$	$34\frac{1}{9}$	$39\frac{1}{9}$	$44\frac{1}{9}$	$49\frac{1}{9}$	$54\frac{1}{9}$	$59\frac{1}{9}$	$63\frac{3}{9}$	$69\frac{1}{9}$	$74\frac{1}{9}$	17
$\frac{1}{8}$	$3\frac{3}{8}$	$5\frac{3}{8}$	$7\frac{3}{8}$	$9\frac{1}{8}$	$11\frac{1}{8}$	$13\frac{1}{8}$	$15\frac{1}{8}$	$17\frac{1}{8}$	$19\frac{1}{8}$	$21\frac{1}{8}$	23	25	27	$28\frac{7}{8}$	18
$\frac{2}{9}$	$7\frac{1}{9}$	11	$14\frac{2}{9}$	$18\frac{1}{9}$	$22\frac{1}{9}$	26	$29\frac{2}{9}$	$33\frac{1}{9}$	37	$40\frac{2}{9}$	$44\frac{1}{9}$	$48\frac{1}{9}$	52	$55\frac{2}{9}$	19
$\frac{3}{9}$	$9\frac{1}{9}$	$13\frac{2}{9}$	$18\frac{1}{9}$	$22\frac{2}{9}$	$27\frac{1}{9}$	32	$36\frac{2}{9}$	$41\frac{1}{9}$	$45\frac{1}{9}$	$50\frac{1}{9}$	$55\frac{1}{9}$	$59\frac{2}{9}$	$64\frac{1}{9}$	$68\frac{2}{9}$	20
$\frac{7}{8}$	$9\frac{3}{8}$	$14\frac{3}{8}$	$19\frac{3}{8}$	$24\frac{3}{8}$	$29\frac{3}{8}$	$34\frac{3}{8}$	$39\frac{1}{8}$	$44\frac{1}{8}$	$49\frac{1}{8}$	$54\frac{1}{8}$	$59\frac{1}{8}$	$64\frac{1}{8}$	$69\frac{1}{8}$	$74\frac{1}{8}$	21
$\frac{1}{6}$	$3\frac{1}{6}$	$5\frac{1}{6}$	7	$8\frac{5}{6}$	$10\frac{1}{6}$	$12\frac{1}{6}$	$14\frac{1}{6}$	$15\frac{5}{6}$	$17\frac{5}{6}$	$19\frac{1}{6}$	$21\frac{1}{6}$	23	$24\frac{5}{6}$	$26\frac{1}{6}$	22
$\frac{5}{8}$	$5\frac{1}{8}$	$8\frac{1}{4}$	11	$13\frac{3}{8}$	$16\frac{1}{8}$	$19\frac{1}{4}$	$22\frac{1}{8}$	25	$27\frac{3}{8}$	$30\frac{1}{8}$	$33\frac{1}{8}$	36	$38\frac{3}{8}$	$41\frac{3}{8}$	23
$\frac{4}{5}$	8	12	16	20	24	28	32	36	$40\frac{1}{5}$	$44\frac{1}{5}$	$48\frac{1}{5}$	$52\frac{1}{5}$	$56\frac{1}{5}$	$60\frac{1}{5}$	24
$\frac{5}{9}$	$8\frac{2}{9}$	$13\frac{1}{9}$	$17\frac{1}{9}$	22	$26\frac{1}{9}$	$30\frac{2}{9}$	$35\frac{1}{9}$	$39\frac{1}{9}$	44	$48\frac{1}{9}$	$52\frac{2}{9}$	$56\frac{1}{9}$	$61\frac{1}{9}$	66	25
$\frac{7}{9}$	$9\frac{1}{9}$	$14\frac{1}{9}$	$19\frac{1}{9}$	$24\frac{1}{9}$	29	34	$38\frac{2}{9}$	$43\frac{2}{9}$	$48\frac{1}{9}$	$53\frac{1}{9}$	$58\frac{1}{9}$	$63\frac{1}{9}$	68	$72\frac{2}{9}$	26
$\frac{8}{9}$	$9\frac{2}{9}$	$14\frac{2}{9}$	$19\frac{2}{9}$	$24\frac{2}{9}$	$29\frac{2}{9}$	$34\frac{2}{9}$	$39\frac{2}{9}$	$44\frac{1}{9}$	$49\frac{1}{9}$	$54\frac{1}{9}$	$59\frac{1}{9}$	$64\frac{1}{9}$	$69\frac{1}{9}$	$74\frac{1}{9}$	27
$\frac{1}{11}$	3	$4\frac{1}{2}$	6	$7\frac{1}{2}$	$9\frac{1}{2}$	$10\frac{1}{2}$	$12\frac{1}{2}$	$13\frac{1}{2}$	$15\frac{1}{2}$	$16\frac{1}{2}$	$18\frac{1}{2}$	20	$21\frac{1}{2}$	23	28
$\frac{2}{11}$	$4\frac{2}{11}$	$7\frac{1}{11}$	$9\frac{2}{11}$	$12\frac{1}{11}$	$14\frac{2}{11}$	$17\frac{1}{11}$	$19\frac{1}{11}$	22	$24\frac{1}{11}$	27	$29\frac{1}{11}$	$31\frac{2}{11}$	$34\frac{1}{11}$	$36\frac{2}{11}$	29
$\frac{3}{11}$	$6\frac{1}{11}$	$9\frac{1}{11}$	$12\frac{1}{11}$	$15\frac{1}{11}$	$18\frac{2}{11}$	$21\frac{2}{11}$	25	28	$31\frac{1}{11}$	$34\frac{1}{11}$	$37\frac{1}{11}$	$40\frac{2}{11}$	$43\frac{2}{11}$	47	30
$\frac{4}{11}$	$7\frac{1}{11}$	$10\frac{2}{11}$	$14\frac{1}{11}$	$18\frac{1}{11}$	$21\frac{3}{11}$	$25\frac{1}{11}$	$29\frac{1}{11}$	$32\frac{3}{11}$	$36\frac{1}{11}$	$40\frac{1}{11}$	$43\frac{2}{11}$	$47\frac{1}{11}$	51	$54\frac{3}{11}$	31
$\frac{5}{11}$	8	12	$16\frac{1}{11}$	$20\frac{1}{11}$	$24\frac{1}{11}$	$28\frac{1}{11}$	$32\frac{1}{11}$	$36\frac{1}{11}$	$40\frac{1}{11}$	$44\frac{1}{11}$	$48\frac{2}{11}$	$52\frac{3}{11}$	$56\frac{2}{11}$	$60\frac{2}{11}$	32
$\frac{6}{11}$	$8\frac{2}{11}$	13	$17\frac{1}{11}$	$21\frac{3}{11}$	$26\frac{1}{11}$	$30\frac{1}{11}$	35	$39\frac{1}{11}$	$43\frac{2}{11}$	48	$52\frac{1}{11}$	$56\frac{3}{11}$	$61\frac{1}{11}$	$65\frac{1}{11}$	33
$\frac{7}{11}$	$9\frac{1}{11}$	$13\frac{2}{11}$	$18\frac{1}{11}$	23	$27\frac{1}{11}$	$32\frac{1}{11}$	$36\frac{2}{11}$	$41\frac{1}{11}$	46	$50\frac{2}{11}$	$55\frac{1}{11}$	60	$64\frac{1}{11}$	$69\frac{1}{11}$	34
$\frac{8}{11}$	$9\frac{1}{11}$	$14\frac{1}{11}$	19	$23\frac{2}{11}$	$28\frac{2}{11}$	$33\frac{1}{11}$	$38\frac{1}{11}$	43	$47\frac{3}{11}$	$52\frac{2}{11}$	$57\frac{1}{11}$	$62\frac{1}{11}$	67	$71\frac{2}{11}$	35
$\frac{9}{11}$	$9\frac{2}{11}$	$14\frac{2}{11}$	$19\frac{1}{11}$	$24\frac{1}{11}$	$29\frac{1}{11}$	$34\frac{1}{11}$	$39\frac{1}{11}$	44	49	54	$58\frac{2}{11}$	$63\frac{2}{11}$	$68\frac{2}{11}$	$73\frac{1}{11}$	36
$\frac{10}{11}$	$9\frac{2}{11}$	$14\frac{2}{11}$	$19\frac{2}{11}$	$24\frac{2}{11}$	$29\frac{2}{11}$	$34\frac{2}{11}$	$39\frac{2}{11}$	$44\frac{2}{11}$	$49\frac{2}{11}$	$54\frac{2}{11}$	$59\frac{2}{11}$	$64\frac{1}{11}$	$69\frac{1}{11}$	$74\frac{1}{11}$	37
$\frac{1}{12}$	$2\frac{2}{3}$	$4\frac{1}{2}$	$5\frac{5}{6}$	$7\frac{1}{2}$	$8\frac{1}{2}$	10	$11\frac{1}{2}$	13	$14\frac{1}{2}$	$15\frac{5}{6}$	$17\frac{1}{2}$	$18\frac{5}{6}$	$20\frac{1}{2}$	$21\frac{2}{3}$	38
$\frac{7}{12}$	$8\frac{1}{4}$	$12\frac{1}{4}$	$16\frac{3}{4}$	21	$25\frac{1}{4}$	$29\frac{1}{4}$	$33\frac{3}{4}$	38	$42\frac{1}{4}$	$46\frac{1}{4}$	$50\frac{3}{4}$	55	$59\frac{1}{4}$	$63\frac{1}{4}$	39
$\frac{11}{12}$	$9\frac{3}{4}$	$14\frac{3}{4}$	$19\frac{3}{4}$	$24\frac{3}{4}$	$29\frac{3}{4}$	$34\frac{3}{4}$	$39\frac{3}{4}$	$44\frac{3}{4}$	$49\frac{3}{4}$	$54\frac{3}{4}$	$59\frac{3}{4}$	$64\frac{3}{4}$	$69\frac{3}{4}$	$74\frac{3}{4}$	40

VII.

A TABLE

Shewing the average Pressure of the Steam upon the Piston throughout the Stroke, when cut off in the Cylinder from $\frac{1}{2}$ to $\frac{11}{12}$, commencing with 10lbs and advancing in 5lbs up to 150lbs Pressure.

	Pressure in lbs. at the commencement of the Stroke.														
	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
	Average Pressure in lbs. upon the Piston.														
1	56	59½	63	66½	70	73	77½	80½	84	87½	91	94½	98	101½	105
2	75	79½	84½	89	93¾	98¼	103	107¾	112½	117	121¾	126½	131	135¾	140½
3	47¾	50¾	53¾	56¾	59¾	62¾	65½	68½	71½	74½	77½	80½	83½	86½	89½
4	67¾	72	76¼	80½	84¾	89	93¼	97¼	101½	105¾	110	114¼	118½	122¾	127
5	77¼	82	87	91¾	96½	101¼	106¼	111	115¾	120¾	125½	130¼	135¼	140	144¾
6	41¾	44¼	47	49½	52¼	54¾	57¼	60	62½	65¼	67¾	70½	73	75½	78½
7	61¼	65	69	72¾	76½	80¼	84¼	88	91¾	95¾	99½	103¼	107¼	111	115
8	72½	77	81½	86	90½	95¼	99½	104¼	108¾	113¼	117¾	122¼	126¾	131½	135
9	78¼	83	88	92¾	97¾	102¾	107½	112½	117½	122¼	127¼	132	136¾	141¾	146¾
10	37½	39½	41¾	44¼	46½	48¾	51¼	53½	55¾	58	60½	62¾	65	67½	69¾
11	78¾	83¾	88¾	93½	98½	103½	108¼	113¼	118¼	123¼	128	133	137¾	142¾	147
12	33¼	35¾	37¾	40	42	44	46¼	48¼	50½	52½	54¾	56¾	58¾	61	63
13	51½	54½	57¾	61	64¼	67½	70¾	74	77¼	80½	83½	86¾	90	93¼	96½
14	63¼	67¼	71¼	75¼	79	83	87	91	94¾	98¾	102¼	106¾	110¾	114¾	118¾
15	71¼	75¾	80	84½	89	93½	98	102¼	106¾	111½	115¾	120¼	124¾	129¼	133½
16	76¼	81	85¾	90¾	95½	100¼	105	109¾	114½	119¼	124	128¾	133½	138½	143¼
17	79	84	89	93¾	98¾	103¾	108¾	113¾	118¾	123½	128½	133½	138½	143½	148¼
18	30¾	32¾	34½	36½	38½	40½	42¾	44½	46¼	48	50	52	54¼	56¼	57¾
19	59½	63	66¾	70½	74¼	78	81¾	85½	89	92¾	96½	100¼	104	107¾	111½
20	73½	78	82½	87¼	91¾	96½	101	105½	110¼	114¾	119½	124	128½	133¼	137¾
21	79¼	84½	89½	94¼	99	104	109	114	119	124	128¾	133¾	138¾	143¾	148¾
22	28¼	30½	31¾	33¾	35½	37¼	39	40¾	42½	44¼	46	47¾	49½	51½	53¼
23	44½	47¼	55	57¾	55½	58¼	61	63¾	66¾	69½	72¼	75	77¾	79½	83
24	64¼	68½	72¼	76¼	80½	84½	88½	92½	96½	100½	104½	108½	112½	116½	120½
25	70½	74¾	79¼	83¾	88	92½	97	101¼	105¾	110¼	114½	119	123¼	127¾	132¼
26	77¾	82¾	87½	92¼	97¼	102	107	111¾	116¾	121½	126½	131¼	136¼	141	145
27	79¼	84½	89¼	94¼	99½	104¼	109¼	114¼	119¼	124	129	134	139	144	149
28	24¼	26¼	27¾	29¼	30¾	32¼	33¾	35½	37	38½	40	41½	43¼	44¾	46¼
29	39¼	41¾	44¼	46¾	49	51½	54	56½	59	61¼	63¾	66¼	68¾	71¼	73¾
30	50	53½	56¼	59½	62½	65¾	68¾	72	75¼	78¼	81½	84½	87¾	90¾	94
31	58½	62	65¾	69½	73	76¾	80¼	84	87¾	91¼	95	98½	102¼	106	109½
32	65	69	73	77	81¼	85¼	89¼	93½	97½	101½	105½	109¾	113¾	117¾	121¾
33	70	74¼	78¾	83	87½	91¾	96¼	100¾	105	109½	113¾	118¼	122½	127	131
34	73¾	78½	83	87¾	92¼	97	101½	106¼	110¾	115½	120	124¾	129¼	133¾	138½
35	76¾	81½	86¼	91	95¾	100½	105¼	110¼	115	119¾	124½	129¼	134¼	139	143½
36	78½	83½	88¼	93¼	98¼	103	108	112¾	117¾	122¾	127½	132½	137½	142¼	147¼
37	79½	84½	89½	94½	99½	104½	109½	114½	119¼	124¼	129¼	134¼	139¼	144¼	149¼
38	23¼	24½	26	27½	29	30½	31¾	33¼	34¾	35¼	37¾	39	40½	42	43½
39	67¾	72	76¼	80½	84¾	89	93¼	97½	101½	105¾	110	114¼	118½	122¾	127
40	79½	84½	89½	94½	99½	104½	109½	114½	119½	124½	129½	134½	139½	144½	149½

VIII.

IMPERIAL STANDARD MEASURES.

1.—MEASURE OF LENGTH.

12 inches	1 foot.									
36	3	1 yard.								
198	16½	5½	1 pole or perch.							
7920	660	220	40	1 furlong.						
63360	5280	1760	320	8	1 English mile.					
		2240			1 Irish "					
		1984			1 Scotch "					

SPECIAL MEASURES OF LENGTH.

Nautical Measure.		*Land Measure.*		
1 nautical mile	6082·66 feet.	7·92	inches	1 link.
3 miles	1 league.	100	links	1 chain.
20 leagues	1 degree.	80	chains	1 mile.
360 degrees = earth's circumference.		69·121	miles	1 geo. deg.

6 feet = 1 fathom—used in measuring ropes, chains, &c.

2.—MEASURES OF CAPACITY.

General Measure of Solidity.

1728 cubic inches	... ...	1 cubic foot.
27 cubic feet	... ...	1 cubic yard.
42 cubic feet	... ...	1 ton of shipping.

3.—IMPERIAL GALLON MEASURE FOR LIQUIDS, CORN, &c.

WATER. Cubic Inches.	Lbs. oz.									
8·665	¼	1 gill.								
34·659	1¼	4 ...	1 pint.							
69·818	2½	8 ...	2 ...	1 quart.						
277·274	10	32 ...	8 ...	4 ...	1 gallon.					
554·548	20	64 ...	16 ...	8 ...	2 ...	1 peck.				
2218·19	80	256 ...	64 ...	32 ...	8 ...	4 ...	1 bush.			
17745·5	640	2048 ...	512 ...	256 ...	64 ...	32 ...	8 ...	1 qr.		

1 gallon of sea water weighs...	...	10·32lbs	avoirdupois.
1 " oil ...	" ...	...	9·32	"
1 " proof spirits	" ...	...	9·3	"

Thirty-two gallons of proof spirits in winter will, without being diluted, measure thirty-three in summer.

All fluids expand with heat, and contract with cold down to 40 degrees, but expand when freezing. 32, freezing point; 56, temperate heat; 76, summer heat; 98, blood heat; 112, fierce heat; 176, spirits of wine boil; 212, water boils, when the pressure of the atmosphere is 15lbs to the square inch; if the pressure be less, water boils at a less temperature.

These temperatures are Fahrenheit—by which we are guided in England. The centrigrade rule is used in France, where the freezing point is zero, or 0, and the boiling point 100°. Reaumur's rule is used by many continental nations. Freezing point, or zero, 0, and boiling point 80°.

4.—TROY WEIGHT.

24 grains	1 pennyweight.					
480	20	1 ounce.				
5760	240	12	1 pound.			

By this weight are weighed gold, silver, jewels, electuaries, and all liquors.

The standard for gold coin is 22 carats of fine gold and 2 carats of copper melted together. For silver, 11 oz. 2 dwts. of fine silver, and 18 dwts. of copper.

100lbs 1 cwt. 20 cwt. 1 ton of gold or silver.

To reduce pounds troy into avoirdupois, multiply by 144, and divide by 175, the quotient will be the number of pounds avoirdupois.

5.—AVOIRDUPOIS WEIGHT.

16 drams	1 ounce.					
256	16	1 pound.				
3584	224	14	1 stone.			
7168	448	28	2	1 quarter.		
28672	1792	112	8	4	1 cwt.	
573440	35840	2240	160	80	20 ...	1 ton.

A keel of coal at Newcastle is 21 tons 4 cwt., and a chaldron is 53 cwt. A chaldron of coal in London is 28½ cwt.

About 426	cubic inches	of cast iron	1 cwt.
8520	„	or nearly 5 cubic feet ...	1 ton.
13	cubic feet	of stone	1 „
23	„	sand	1 „
29	„	coal	1 „
38	„	tallow	1 „
39	„	oil	1 „
40	„	rough timber ...	1 „
50	„	squared timber ...	1 „

6.—MEASURE OF SURFACES.

144 inches	1 square foot.					
1296	9	1 square yard.				
39204	272¼.....	30¼.....	1 square pole.			
1568160	10890	1210	40	1 rood.		
6272640	43560	4840	160	4	1 acre.	

By this measure are measured all things that have length and breadth, such as land, painting, plastering, flooring, thatching, plumbing, glazing, &c.

X.

RULE

TO ASCERTAIN THE WEIGHT OF CAST-IRON BALLS OF ANY DIAMETER.

Cube the diameter and divide by 7·27. The quotient is the weight.

EXAMPLE :

```
                9
                9
               ---
               81
                9          2
            ---------     -----
   7·27 ) 729·00 ( 100    7·27lbs
          727 · ·
          -------
            2·00
```

BOILING POINT OF WATER

UNDER DIFFERENT PRESSURES OF THE ATMOSPHERE.

Barometer.	Pressure.	Boiling Point.
26 inches	13lbs per square inch	205 degrees.
26½ "	13¼ "	205¾ "
27 "	13½ "	206½ "
27½ "	13¾ "	207¼ "
28 "	14 "	208¼ "
28½ "	14¼ "	209¼ "
29 "	14½ "	210¼ "
29½ "	14¾ "	211 "
30 "	15 "	212 "
30½ "	15¼ "	212¾ "
31 "	15½ "	213¾ "

Water in vacuum boils at about 98 degrees Fahrenheit, and assumes a solid at 32 degrees in the atmosphere, when it expands $\frac{1}{11}$th its original bulk. At a temperature of 212 degrees it becomes vapour, or steam, nor can that temperature be increased in an open vessel. In a closed one it may be heated to redness. Mercury will fall $\frac{1}{10}$th of an inch for every 100 feet perpendicular height. In ascending Snowden, in North Wales, the mercury fell $3\frac{8}{10}$ inches, 3,720 feet above the sea. The velocity of wind in a strong gale is 30 to 35 miles per hour; hard gale, 40 to 45; storm, 50 to 55; and a hurricane, 80 to 100 miles per hour.

GEOMETRY.

45 degrees — ⅛ of a circle.
90 " — 1 quadrant, or quarter of a circle.
360 " — 1 circle. When divided into parts are called degrees.

Many calculations are founded on this division of the circle.

Weight of Cast-iron Balls from 3 to 12 inches in diameter. Useful for Safety Valves, &c.

Diameter in Inches.....	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7
Weight in lbs	3¾	4¾	5¾	7¼	8¾	10½	12½	14¾	17	20	23	26	29¾	33½	37¾	42¼	47¼

Diameter in Inches.....	7¼	7½	7¾	8	8¼	8½	8¾	9	9¼	9½	9¾	10	10¼	10½	10¾	11	11½
Weight in lbs	52½	58	64	70½	77¼	84½	92¼	100¼	109	118	127½	137¾	148¼	159¼	171	183¼	209½

Diameter in Inches.....	12	13															
Weight in lbs	238	302															

Weight of Cast-iron Plates per superficial foot as per Thickness.

Thickness in Inches	⅛	¼	⅜	½	⅝	¾	⅞	1	
	lbs ozs	lbs ozs	lbs ozs	lbs ozs	lbs ozs	lbs ozs	lbs ozs	lbs ozs	
Weight	4 13	9 10	14 8	19 5	24 2	29 0	33 13	38 10	

Weight of Boiler Plates 1 foot square, and from $\frac{1}{16}$th of an inch Thick.

Thickness in Inches	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
Weight in lbs per foot sq.....	$2\frac{1}{2}$	5	$7\frac{1}{2}$	10	$12\frac{1}{2}$	15	$17\frac{1}{2}$	20	$22\frac{1}{2}$	25	$27\frac{1}{2}$	30	$32\frac{1}{2}$	35	$37\frac{1}{2}$	40

Weight of Square Bar-iron, from ½ inch to 6 inches Square, 1 foot Long.

For Calculating the Weight of Shafting, &c.

Square	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$
Weight in lbs	$\frac{5}{16}$	$1\frac{1}{4}$	2	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{2}$	$7\frac{1}{2}$	9	$10\frac{1}{2}$	12	$13\frac{1}{2}$	$15\frac{1}{4}$	17	19	21

Square	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4	$4\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{3}{8}$	$4\frac{1}{2}$	$4\frac{5}{8}$
Weight in lbs	$23\frac{1}{4}$	$25\frac{1}{2}$	28	$30\frac{1}{2}$	33	$35\frac{3}{4}$	$38\frac{1}{2}$	$41\frac{1}{2}$	$44\frac{1}{2}$	$47\frac{1}{2}$	$50\frac{3}{4}$	54	$57\frac{1}{2}$	61	$64\frac{3}{4}$	$68\frac{1}{2}$	$72\frac{1}{4}$

Square	$4\frac{3}{4}$	$4\frac{7}{8}$	5	$5\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{3}{4}$	6										
Weight in lbs	$76\frac{1}{4}$	$80\frac{1}{4}$	$84\frac{1}{2}$	$93\frac{1}{4}$	$102\frac{1}{4}$	$111\frac{3}{4}$	$121\frac{3}{4}$										

Diameter in Inches.....	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$
Weight in lbs	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{4}$	5	6	7	8	$9\frac{1}{4}$	$10\frac{1}{2}$	12	$13\frac{1}{2}$	15	$16\frac{3}{4}$

Diameter in Inches.....	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4	$4\frac{1}{8}$	$4\frac{1}{4}$	$4\frac{3}{8}$	$4\frac{1}{2}$	$4\frac{5}{8}$
Weight in lbs	$18\frac{1}{4}$	20	22	24	26	28	$30\frac{1}{4}$	$32\frac{1}{2}$	35	$37\frac{1}{2}$	40	$42\frac{1}{2}$	$45\frac{1}{2}$	48	$50\frac{3}{4}$	$53\frac{3}{4}$	$56\frac{3}{4}$

Diameter in Inches.....	$4\frac{3}{4}$	$4\frac{7}{8}$	5	$5\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{3}{4}$	6										
Weight in lbs	60	63	$66\frac{3}{4}$	$73\frac{1}{2}$	$80\frac{1}{4}$	$87\frac{3}{4}$	$95\frac{1}{2}$										

Weight of Sheet Lead per superficial foot, as per Thickness.

Thickness in Inches	$\frac{1}{16}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{3}{4}$	1
Weight in lbs	$3\frac{1}{4}$	5	6	$7\frac{1}{2}$	10	12	$14\frac{3}{4}$	$19\frac{3}{4}$	$29\frac{1}{2}$	$44\frac{1}{4}$	59

XIV.

Weight of Cast-iron Pipes 1 foot in Length, from $\frac{1}{4}$ inch to $1\frac{1}{4}$ inch Thick, and from 3 to 24 inches Diameter.

Diameter of Bore in Inches.	THICKNESS IN INCHES.								
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
3	$8\frac{1}{2}$	$12\frac{1}{2}$	$17\frac{1}{4}$	$22\frac{1}{4}$	$27\frac{1}{2}$				
$3\frac{1}{2}$	$9\frac{1}{4}$	$14\frac{1}{4}$	$19\frac{1}{2}$	$25\frac{1}{4}$	$31\frac{1}{4}$				
4	10	$16\frac{3}{4}$	22	$28\frac{1}{2}$	35				
$4\frac{1}{2}$	$11\frac{3}{4}$	18	$24\frac{1}{2}$	$31\frac{1}{2}$	$38\frac{3}{4}$				
5	13	$19\frac{3}{4}$	27	$34\frac{1}{2}$	$42\frac{1}{4}$	$50\frac{1}{2}$	59		
$5\frac{1}{2}$	15	$21\frac{1}{2}$	$29\frac{1}{2}$	$37\frac{1}{2}$	46	$54\frac{3}{4}$	$63\frac{3}{4}$		
6		$23\frac{1}{2}$	32	$40\frac{3}{4}$	$49\frac{3}{4}$	59	$68\frac{3}{4}$	$78\frac{3}{4}$	$88\frac{3}{4}$
$6\frac{1}{2}$		$25\frac{1}{4}$	$34\frac{1}{2}$	$43\frac{3}{4}$	$53\frac{1}{2}$	$63\frac{1}{2}$	$73\frac{1}{2}$	$84\frac{1}{4}$	95
7		$27\frac{1}{4}$	$36\frac{3}{4}$	$46\frac{3}{4}$	$56\frac{3}{4}$	$67\frac{3}{4}$	$78\frac{1}{2}$	$89\frac{3}{4}$	$101\frac{1}{4}$
$7\frac{1}{2}$		29	39	50	$60\frac{3}{4}$	72	$83\frac{1}{2}$	$95\frac{1}{4}$	$107\frac{1}{2}$
8		$30\frac{3}{4}$	$41\frac{3}{4}$	53	$64\frac{1}{2}$	$76\frac{1}{4}$	$88\frac{1}{2}$	$100\frac{3}{4}$	$113\frac{1}{2}$
$8\frac{1}{2}$		33	$44\frac{1}{2}$	$56\frac{1}{4}$	$68\frac{1}{4}$	$80\frac{3}{4}$	$93\frac{1}{2}$	$106\frac{1}{2}$	120
9		$34\frac{1}{2}$	$46\frac{1}{2}$	59	$71\frac{3}{4}$	$84\frac{3}{4}$	$98\frac{1}{2}$	$111\frac{3}{4}$	$125\frac{3}{4}$
$9\frac{1}{2}$		$36\frac{1}{4}$	49	62	$75\frac{1}{2}$	89	103	$117\frac{1}{2}$	132
10		$38\frac{1}{4}$	$51\frac{1}{2}$	$65\frac{1}{4}$	$79\frac{1}{4}$	$93\frac{1}{2}$	108	$122\frac{3}{4}$	138
$10\frac{1}{2}$			54	$68\frac{1}{4}$	$82\frac{3}{4}$	$97\frac{3}{4}$	$112\frac{3}{4}$	$128\frac{1}{2}$	$144\frac{1}{4}$
11			$56\frac{1}{2}$	$71\frac{1}{4}$	$86\frac{1}{2}$	102	$117\frac{3}{4}$	134	$150\frac{1}{4}$
$11\frac{1}{2}$			59	$76\frac{1}{4}$	90	$106\frac{1}{4}$	$122\frac{3}{4}$	$139\frac{1}{2}$	$156\frac{1}{2}$
12			$61\frac{1}{4}$	$77\frac{1}{2}$	$93\frac{1}{2}$	$110\frac{1}{2}$	$127\frac{1}{2}$	145	$162\frac{1}{2}$
13				$82\frac{3}{4}$	$101\frac{1}{4}$	$118\frac{1}{4}$	$137\frac{1}{2}$	154	$173\frac{1}{2}$
14				$89\frac{1}{4}$	$108\frac{1}{4}$	$126\frac{1}{2}$	$146\frac{1}{4}$	$165\frac{1}{4}$	$185\frac{1}{4}$
15				$95\frac{1}{4}$	$115\frac{3}{4}$	$135\frac{1}{4}$	$156\frac{1}{4}$	$176\frac{1}{4}$	198
16					$123\frac{1}{4}$	143	166	$187\frac{1}{2}$	$211\frac{1}{4}$
17					$130\frac{1}{4}$	$152\frac{1}{2}$	$178\frac{1}{2}$	$198\frac{1}{4}$	$223\frac{1}{2}$
18					137	$161\frac{1}{4}$	$185\frac{1}{4}$	209	$235\frac{1}{4}$
19						$169\frac{1}{4}$	$195\frac{3}{4}$	$222\frac{1}{4}$	247
20						178	$205\frac{1}{4}$	$233\frac{1}{4}$	259
21							214	$243\frac{1}{2}$	$273\frac{1}{4}$
22							2232	$254\frac{3}{4}$	$285\frac{1}{4}$
23							$233\frac{1}{2}$	$265\frac{1}{2}$	$298\frac{1}{4}$
24							$245\frac{1}{4}$	$277\frac{1}{2}$	$310\frac{1}{2}$

XV.

WEIGHT OF MATERIALS.

	Weight of a cubic foot in lbs.	Weight of a cubic inch in ozs.	No. of cubic inches in a lb.	Weight of a cubic inch in lbs.
Mercury	848	7·851	2·037	·4908
Lead	709	6·456	2·437	·4103
Bar Iron..... ...	477	4·140	3·623	·276
Cast Iron	454⅛	4·203	3·802	·263
Sheet Copper ...	557¼	5·159	3·103	·3225
Cast Copper ...	549¼	5·086	3·146	·3178
Cast Brass	524¾	4·852	3·223	·3037
Brick	125	1·456	13·824	·0723
Stone	151	1·396	11·443	·0873
Water.....	62½		27½	

Thirty-six feet of common water make 1 ton. 35 feet of sea water make 1 ton.

One cubic foot of water = 6¼ imperial gallons, or 62½lbs. 1 cylindrical foot = 5 gallons, or 49lbs.

11·2 imperial gallons = 1 cwt. 224 imperial gallons = 1 ton. 1 gallon of fresh water = 10lbs. 1 gallon of sea water = 10·25lbs.

At a temperature of 62° Fahrenheit, between 62° and 42°, water attains its greatest density; and the pressure is as the perpendicular height, independent of quantity.

Water is not compressible. It presses in every direction, and finds a level; thus a small quantity will balance and support a great quantity, whatever the difference in dimension.

The centre of the pressure of a column of water is two-thirds of its depth from the surface.

Ten pounds of distilled or rain water equals the standard gallon, at 62°.

2·004 inches of a column of mercury...			...	1lb.
27·648	„	„	water	1lb.
26·895	„	„	sea water ...	1lb.

XVI.

A TABLE:

SHEWING THE DIFFERENCE IN THE STRENGTH OF METALS.

Wrought Iron	1000	Gold	273
Copper	550	Zinc	199
Platinum	494	Tin	63
Silver	349	Lead	50

A copper bolt or rod of the same thickness as iron, will sustain little more than one-half the weight iron will. Iron wire, one-sixteenth of an inch diameter, is capable of sustaining a weight of 500lbs. A bar of wrought-iron one inch square, when sound and good, will require 25 tons to pull it asunder.

HEAT-CONDUCTING POWERS OF DIFFERENT METALS.

Gold	1000	Iron	374
Silver	973	Zinc	368
Copper	898	Tin	304
Platinum	391	Lead	108

A TABLE:

SHEWING THE TEMPERATURE METALS MELT AT.

	Degrees.		Degrees.
Gold	2016	Lead	612
Platinum	3280	Tin	442
Silver	1873	Zinc	773
Copper	1996	Cast Iron	2786
Brass	1900	Mercury, boils	672

Tin 2 parts, lead 2 parts, mixed, melts at 332°.

With cast-iron, melted from the pig, its strength may be represented by 1; the second time by 1½; the third time by 2, and so on until it has been melted nine or ten times, when it will have attained its maximum strength—that being about four times the strength of the first casting. This shews how important it is to have all toothed wheels, particularly the first driving wheels, beams, cranks, shafts, or other parts of a Steam Engine and going gear, made from good old metal, and not new pig-iron. By being re-melted, the metal becomes refined, closer in the pores, works smoother, and wears longer.

Metal melted in a blast furnace is not equal in strength to the same metal melted in an air furnace.

A TABLE FOR SAFETY VALVES, CYLINDERS, AIR-PUMPS, &c.,

Containing the Circumferences and Areas of Circles from $\frac{1}{16}$ of an inch to 10 inches, advancing by $\frac{1}{16}$ of an inch; and by $\frac{1}{8}$ of an inch, from 10 inches to 100 inches Diameter.

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
$\frac{1}{16}$	.1963	.0030	2 in.	6.2832	3.1416
$\frac{1}{8}$	.3927	.0122	$\frac{1}{16}$	6.4795	3.3411
$\frac{3}{16}$	.5890	.0276	$\frac{1}{8}$	6.6759	3.5465
$\frac{1}{4}$	.7854	.0490	$\frac{3}{16}$	6.8722	3.7582
$\frac{5}{16}$	.9817	.0767	$\frac{1}{4}$	7.0686	3.9760
$\frac{3}{8}$	1.1781	.1104	$\frac{5}{16}$	7.2649	4.2001
$\frac{7}{16}$	1.3744	.1503	$\frac{3}{8}$	7.4613	4.4302
$\frac{1}{2}$	1.5708	.1963	$\frac{7}{16}$	7.6576	4.6664
$\frac{9}{16}$	1.7671	.2485	$\frac{1}{2}$	7.8540	4.9087
$\frac{5}{8}$	1.9635	.3068	$\frac{9}{16}$	8.0503	5.1573
$\frac{11}{16}$	2.1598	.3712	$\frac{5}{8}$	8.2467	5.4119
$\frac{3}{4}$	2.3562	.4417	$\frac{11}{16}$	8.4430	5.6727
$\frac{13}{16}$	2.5525	.5185	$\frac{3}{4}$	8.6394	5.9395
$\frac{7}{8}$	2.7489	.6013	$\frac{13}{16}$	8.8357	6.2126
$\frac{15}{16}$	2.9452	.6903	$\frac{7}{8}$	9.0321	6.4918
			$\frac{15}{16}$	9.2284	6.7772
1 in.	3.1416	.7854			
$\frac{1}{16}$	3.3379	.8861	3 in.	9.4248	7.0686
$\frac{1}{8}$	3.5343	.9940	$\frac{1}{16}$	9.6211	7.3662
$\frac{3}{16}$	3.7306	1.1075	$\frac{1}{8}$	9.8175	7.6699
$\frac{1}{4}$	3.9270	1.2271	$\frac{3}{16}$	10.0138	7.9798
$\frac{5}{16}$	4.1233	1.3529	$\frac{1}{4}$	10.2102	8.2957
$\frac{3}{8}$	4.3197	1.4848	$\frac{5}{16}$	10.4065	8.6179
$\frac{7}{16}$	4.5160	1.6229	$\frac{3}{8}$	10.6029	8.9462
$\frac{1}{2}$	4.7124	1.7671	$\frac{7}{16}$	10.7992	9.2806
$\frac{9}{16}$	4.9087	1.9175	$\frac{1}{2}$	10.9956	9.6211
$\frac{5}{8}$	5.1051	2.0739	$\frac{9}{16}$	11.1919	9.9678
$\frac{11}{16}$	5.3014	2.2365	$\frac{5}{8}$	11.3883	10.3206
$\frac{3}{4}$	5.4978	2.4052	$\frac{11}{16}$	11.5846	10.6796
$\frac{13}{16}$	5.6941	2.5801	$\frac{3}{4}$	11.7810	11.0446
$\frac{7}{8}$	5.8905	2.7611	$\frac{13}{16}$	11.9773	11.4159
$\frac{15}{16}$	6.0868	2.9483	$\frac{7}{8}$	12.1737	11.7932

Diameter.	Circum.	Area.	Diameter.	Circum.	Area
$\frac{15}{16}$	12.3700	12.1768	$\frac{1}{2}$	20.4204	33.1831
			$\frac{9}{16}$	20.6167	33.8244
4 in.	12.5664	12.5664	$\frac{5}{8}$	20.8131	34.4717
$\frac{1}{16}$	12.7627	12.9622	$\frac{11}{16}$	21.0094	35.1252
$\frac{1}{8}$	12.9591	13.3640	$\frac{3}{4}$	21.2058	35.7847
$\frac{3}{16}$	13.1554	13.7721	$\frac{13}{16}$	21.4021	36.4505
$\frac{1}{4}$	13.3518	14.1862	$\frac{7}{8}$	21.5985	37.1224
$\frac{5}{16}$	13.5481	14.6066	$\frac{15}{16}$	21.7948	37.8005
$\frac{3}{8}$	13.7445	15.0331			
$\frac{7}{16}$	13.9408	15.4657	7 in.	21.9912	38.4846
$\frac{1}{2}$	14.1372	15.9043	$\frac{1}{16}$	22.1875	39.1749
$\frac{9}{16}$	14.3335	16.3492	$\frac{1}{8}$	22.3839	39.8713
$\frac{5}{8}$	14.5299	16.8001	$\frac{3}{16}$	22.5802	40.5469
$\frac{11}{16}$	14.7262	17.2573	$\frac{1}{4}$	22.7766	41.2825
$\frac{3}{4}$	14.9226	17.7205	$\frac{5}{16}$	22.9729	41.9974
$\frac{13}{16}$	15.1189	18.1900	$\frac{3}{8}$	23.1693	42.7184
$\frac{7}{8}$	15.3153	18.6655	$\frac{7}{16}$	23.3656	43.4455
$\frac{15}{16}$	15.5716	19.1472	$\frac{1}{2}$	23.5620	44.1787
			$\frac{9}{16}$	23.7583	44.9181
5 in.	15.7080	19.6350	$\frac{5}{8}$	23.9547	45.6636
$\frac{1}{16}$	15.9043	20.1290	$\frac{11}{16}$	24.1510	46.4153
$\frac{1}{8}$	16.1007	20.6290	$\frac{3}{4}$	24.3474	47.1730
$\frac{3}{16}$	16.2970	21.1252	$\frac{13}{16}$	24.5437	47.9370
$\frac{1}{4}$	16.4934	21.6475	$\frac{7}{8}$	24.7401	48.7070
$\frac{5}{16}$	16.6897	22.1661	$\frac{15}{16}$	24.9364	49.4833
$\frac{3}{8}$	16.8861	22.6907			
$\frac{7}{16}$	17.0824	23.2215	8 in.	25.1328	50.2656
$\frac{1}{2}$	17.2788	23.7583	$\frac{1}{16}$	25.3291	51.0541
$\frac{9}{16}$	17.4751	24.3014	$\frac{1}{8}$	25.5255	51.8486
$\frac{5}{8}$	17.6715	24.8505	$\frac{3}{16}$	25.7218	52.8994
$\frac{11}{16}$	17.8678	25.4058	$\frac{1}{4}$	25.9182	53.4562
$\frac{3}{4}$	18.0642	25.9672	$\frac{5}{16}$	26.1145	54.2748
$\frac{13}{16}$	18.2605	26.5348	$\frac{3}{8}$	26.3109	55.0885
$\frac{7}{8}$	18.4569	27.1085	$\frac{7}{16}$	26.5072	55.9138
$\frac{15}{16}$	18.6532	27.6884	$\frac{1}{2}$	26.7036	56.7451
			$\frac{9}{16}$	26.8999	57.5887
6 in.	18.8496	28.2744	$\frac{5}{8}$	27.0963	58.4264
$\frac{1}{16}$	19.0459	28.8665	$\frac{11}{16}$	27.2926	59.7762
$\frac{1}{8}$	19.2423	29.4647	$\frac{3}{4}$	27.4890	60.1321
$\frac{3}{16}$	19.4386	30.0798	$\frac{13}{16}$	27.6853	60.9943
$\frac{1}{4}$	19.6350	30.6796	$\frac{7}{8}$	27.8817	61.8625
$\frac{5}{16}$	19.8313	31.2964	$\frac{15}{16}$	27.0780	62.7369
$\frac{3}{8}$	20.0277	31.9192			
$\frac{7}{16}$	20.2240	32.5481	9 in.	28.2744	63.6174

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
1/16	28.4707	64.5041	1/8	41.2338	135.2974
1/8	28.6671	65.3968	1/4	41.6262	137.8867
3/16	28.8634	66.2957	3/8	42.0189	140.5007
1/4	29.0598	67.2007	1/2	42.4116	143.1391
5/16	29.2561	68.1120	5/8	42.8043	145.8021
3/8	29.4525	69.0293	3/4	43.1970	148.4896
7/16	29.6488	69.9528	7/8	43.5897	151.2017
1/2	29.8452	70.8823			
9/16	30.0415	71.8181	14 in.	43.9824	153.9384
5/8	30.2379	72.7599	1/8	44.3751	156.6995
11/16	30.4342	73.7079	1/4	44.7676	159.4852
3/4	30.6306	74.6620	3/8	45.1605	162.2956
13/16	30.8269	75.6223	1/2	45.5532	165.1303
7/8	31.0233	76.5887	5/8	45.9459	167.9896
15/16	31.2196	77.5613	3/4	46.3386	170.8735
			7/8	46.7313	173.7820
10 in.	31.4160	78.5400			
1/8	31.8087	80.5157	15 in.	47.1240	176.7150
1/4	32.2014	82.5160	1/8	47.5167	179.6725
3/8	32.5941	84.5409	1/4	47.9094	182.6545
1/2	32.9868	86.5903	3/8	48.3021	185.6612
5/8	33.3795	88.6643	1/2	48.6948	188.6923
3/4	33.7722	90.7627	5/8	49.0875	191.7480
7/8	34.1649	92.8858	3/4	49.4802	194.8282
			7/8	49.8729	197.9330
11 in.	34.5576	95.0334			
1/8	34.9503	97.2053	16 in.	50.2656	201.0624
1/4	35.3430	99.4021	1/8	50.6583	204.2162
3/8	35.7357	101.6234	1/4	51.0510	207.3946
1/2	36.1284	103.8691	3/8	51.4437	210.5976
5/8	36.5211	106.1394	1/2	51.8364	213.8251
3/4	36.9138	108.4342	5/8	52.2291	217.0772
7/8	37.3065	110.7536	3/4	52.6218	220.3537
			7/8	53.0145	223.6549
12 in.	37.6992	113.0976			
1/8	38.0919	115.4660	17 in.	53.4072	226.9806
1/4	38.4846	117.8590	1/8	53.7999	230.3308
3/8	38.8773	120.2766	1/4	54.1926	233.7055
1/2	39.2700	122.7187	3/8	54.5853	237.1049
5/8	39.6627	125.1854	1/2	54.9780	240.5287
3/4	40.0554	127.6765	5/8	55.3707	243.9771
7/8	40.4481	130.1923	3/4	55.7634	247.4500
			7/8	56.1561	250.9475
13 in.	43.8408	132.7326			

Diameter.	Circum.	Area.	Diameter.	Circum.	Area
18 in.	56.5488	254.4696	23 in.	72.2568	415.4766
1/8	56.9415	258.0161	1/8	72.6495	420.0049
1/4	57.8342	261.5872	1/4	73.0422	424.5577
3/8	57.7269	265.1829	3/8	73.4349	429.1352
1/2	58.1196	268.8031	1/2	73.8276	433.7371
5/8	58.5123	272.4479	5/8	74.2203	438.3636
3/4	58.9056	276.1171	3/4	74.6130	443.0146
7/8	59.2977	279.8110	7/8	75.0057	447.6992
19 in.	59.6904	283.5294	24 in.	75.3984	452.3904
1/8	60.0831	287.2723	1/8	75.7911	457.1150
1/4	60.4758	291.0397	1/4	76.1838	461.8642
3/8	60.8685	294.8312	3/8	76.5765	466.6380
1/2	61.2612	298.6483	1/2	76.9692	471.4363
5/8	61.6539	302.4894	5/8	77.3619	476.2592
3/4	62.0466	306.3550	3/4	77.7546	481.1065
7/8	62.4393	310.2452	7/8	78.1473	485.9785
20 in.	62.8320	314.1600	25 in.	78.5400	490.8750
1/8	63.2247	318.0992	1/8	78.9327	495.7960
1/4	63.6174	322.0630	1/4	79.3254	500.7415
3/8	64.0101	326.0514	3/8	79.7181	505.7117
1/2	64.4028	330.0643	1/2	80.1108	510.7063
5/8	64.7955	334.1018	5/8	80.5035	515.7255
3/4	65.1882	338.1637	3/4	80.8962	520.7692
7/8	65.5809	342.2503	7/8	81.2889	525.8375
21 in.	65.7936	346.3614	26 in.	81.6816	530.9304
1/8	66.3663	350.4970	1/8	82.0743	536.0477
1/4	66.7590	354.6571	1/4	82.4670	541.1896
3/8	67.1517	358.8419	3/8	82.8597	546.3561
1/2	67.5444	363.0511	1/2	83.2524	551.5471
5/8	67.9371	367.2849	5/8	83.6451	556.7627
3/4	68.3298	371.5432	3/4	84.0378	562.0027
7/8	68.7225	375.8261	7/8	84.4305	567.2674
22 in.	69.1152	380.1336	27 in.	84.8232	572.5566
1/8	69.5079	384.4655	1/8	85.2159	577.8703
1/4	69.9006	388.8220	1/4	85.6086	583.2085
3/8	70.2933	393.2031	3/8	86.0013	588.5714
1/2	70.6860	397.6087	1/2	86.3940	593.9587
5/8	71.0787	402.0388	5/8	86.7867	599.3706
3/4	71.4714	406.4935	3/4	87.1794	604.8070
7/8	71.8641	410.9728	7/8	87.5721	610.2680

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
28 in.	87.9648	615.7536	33 in.	103.6728	855.3006
1/8	88.3575	621.2636	1/8	104.0655	861.7924
1/4	88.7502	626.7982	1/4	104.4582	868.3087
3/8	89.1429	632.3574	3/8	104.8509	874.8497
1/2	89.5356	637.9411	1/2	105.2436	881.4151
5/8	89.9283	643.5494	5/8	105.6363	888.0051
3/4	90.3210	649.1821	3/4	106.0290	894.6196
7/8	90.7137	654.8395	7/8	106.4217	901.2587
29 in.	91.1064	660.5214	34 in.	106.8144	907.9224
1/8	91.4991	666.2278	1/8	107.2071	914.6105
1/4	91.8918	671.9587	1/4	107.5998	921.3232
3/8	92.2845	677.7143	3/8	107.9925	928.0605
1/2	92.6772	683.4943	1/2	108.3852	934.8223
5/8	93.0699	689.2989	5/8	108.7779	941.6086
3/4	93.4626	695.1280	3/4	109.1706	948.4195
7/8	93.8553	700.9817	7/8	109.5633	955.2550
30 in.	94.2480	706.8600	35 in.	109.9560	962.1150
1/8	94.6407	712.7627	1/8	110.3487	968.9995
1/4	95.0334	718.6900	1/4	110.7414	975.9085
3/8	95.4261	724.6419	3/8	111.1341	982.8422
1/2	95.8188	730.6183	1/2	111.5268	989.8003
5/8	96.2115	736.6193	5/8	111.9195	996.7830
3/4	96.6042	742.6447	3/4	112.3122	1003.7902
7/8	96.9969	748.6948	7/8	112.7049	1010.8220
31 in.	97.3896	754.7694	36 in.	113.0976	1017.8784
1/8	97.7823	760.8685	1/8	113.4903	1024.9592
1/4	98.1750	766.9921	1/4	113.8830	1032.0646
3/8	98.5677	773.1404	3/8	114.2757	1039.1946
1/2	98.9684	779.3131	1/2	114.6684	1046.3941
5/8	99.3531	785.5104	5/8	115.0611	1053.5281
3/4	99.7458	791.7322	3/4	115.4538	1060.7317
7/8	100.1385	797.9786	7/8	115.8465	1067.9599
32 in.	100.5312	804.2496	37 in.	116.2392	1075.2126
1/8	100.9240	810.5450	1/8	116.6319	1082.4898
1/4	101.3166	816.8650	1/4	117.0246	1089.7915
3/8	101.7093	823.2096	3/8	117.4173	1097.1179
1/2	102.1020	829.5787	1/2	117.8100	1104.4687
5/8	102.4947	835.9724	5/8	118.2027	1111.8441
3/4	102.8874	842.3905	3/4	118.5954	1119.2440
7/8	103.2801	848.8333	7/8	118.9881	1126.6685

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
38 in.	119.3808	1134.1176	43 in.	135.0888	1452.2046
1/8	119.7735	1141.5911	1/8	135.4815	1460.6599
1/4	120.1662	1149.0892	1/4	135.8742	1469.1397
3/8	120.5589	1156.6119	3/8	136.2669	1477.6342
1/2	120.9516	1164.1591	1/2	136.6596	1486.1731
5/8	121.3443	1171.7309	5/8	137.0523	1494.7266
3/4	121.7370	1179.3271	3/4	137.4450	1503.3046
7/8	122.1297	1186.9480	7/8	137.8377	1511.9072
39 in.	122.5224	1194.5934	44 in.	138.2304	1520.5341
1/8	122.9151	1202.2633	1/8	138.6231	1529.1860
1/4	123.3078	1209.9577	1/4	139.0158	1537.8622
3/8	123.7005	1217.6768	3/8	139.4085	1546.5530
1/2	124.0932	1225.4203	1/2	139.8012	1555.2883
5/8	124.4859	1233.1884	5/8	140.1939	1564.0382
3/4	124.9787	1240.9810	3/4	140.5866	1572.8125
7/8	125.2713	1248.7982	7/8	140.9793	1581.6115
40 in.	125.6640	1256.6400	45 in.	141.3720	1590.4350
1/8	126.0567	1264.5062	1/8	141.7647	1599.2830
1/4	126.4494	1272.3970	1/4	142.1574	1608.1555
3/8	126.8421	1280.3124	3/8	142.5501	1617.0427
1/2	127.2348	1288.2523	1/2	142.9428	1625.9743
5/8	127.6275	1296.2168	5/8	143.3355	1634.9205
3/4	128.0202	1304.2057	3/4	143.7382	1643.8912
7/8	128.4129	1312.2193	7/8	144.1209	1652.8865
41 in.	128.8056	1320.2574	46 in.	144.5136	1661.9064
1/8	129.1983	1328.3200	1/8	144.9063	1670.9507
1/4	129.5910	1336.4071	1/4	145.2990	1680.0196
3/8	129.9837	1344.5189	3/8	145.6917	1689.1031
1/2	130.3764	1352.6551	1/2	146.0844	1698.2311
5/8	130.7691	1360.8159	5/8	146.4771	1707.3737
3/4	131.1618	1369.0012	3/4	146.8698	1716.5407
7/8	131.5545	1377.2111	7/8	147.2625	1725.7324
42 in.	131.9472	1385.4456	47 in.	147.6552	1734.9486
1/8	132.3399	1393.7045	1/8	148.0479	1744.1893
1/4	132.7326	1401.9880	1/4	148.4406	1753.4545
3/8	133.1253	1470.2961	3/8	148.8333	1762.7344
1/2	133.5180	1418.6287	1/2	149.2260	1772.0587
5/8	133.9107	1426.9859	5/8	149.6187	1781.3976
3/4	134.3034	1435.3675	3/4	150.0114	1790.7610
7/8	134.6961	1443.7738	7/8	150.4041	1800.1490

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
48 in.	150.7968	1809.5616	53 in.	166.5048	2206.1886
1/8	151.1895	1818.9986	1/8	166.8975	2216.6074
1/4	151.5822	1828.4602	1/4	167.2902	2227.0507
3/8	151.9749	1837.9364	3/8	167.6829	2237.5187
1/2	152.3676	1847.4571	1/2	168.0756	2248.0111
5/8	152.7603	1856.9924	5/8	168.4683	2258.5281
3/4	153.1530	1868.5521	3/4	168.8610	2269.0696
7/8	153.5457	1876.1365	7/8	169.2537	2279.6357
49 in.	153.9384	1885.7454	54 in.	169.6464	2290.2264
1/8	154.3311	1895.3788	1/8	170.0391	2300.8415
1/4	154.7238	1905.0367	1/4	170.4318	2311.4812
3/8	155.1165	1914.7093	3/8	170.8245	2322.1455
1/2	155.5092	1924.4263	1/2	171.2172	2332.8343
5/8	155.9019	1934.1579	5/8	171.6099	2343.5477
3/4	156.2946	1943.9140	3/4	172.0026	2354.2855
7/8	156.6873	1953.6947	7/8	172.3593	2365.0480
50 in.	157.0800	1963.5000	55 in.	172.7880	2375.8350
1/8	157.4727	1973.3297	1/8	173.1807	2386.6465
1/4	157.8654	1983.1840	1/4	173.5734	2397.4825
3/8	158.2581	1993.0529	3/8	173.9661	2408.3432
1/2	158.6508	2002.9663	1/2	174.3588	2419.2283
5/8	159.0435	2012.8943	5/8	174.7515	2430.1833
3/4	159.4362	2022.8467	3/4	175.1442	2441.0772
7/8	159.8289	2032.8238	7/8	175.5369	2452.0310
51 in.	160.2216	2042.8254	56 in.	175.9296	2463.0144
1/8	160.6143	2052.8515	1/8	176.3323	2474.0222
1/4	161.0070	2062.9021	1/4	176.7150	2485.3546
3/8	161.3997	2072.9764	3/8	177.1077	2496.1116
1/2	161.7924	2083.0771	1/2	177.5004	2507.1931
5/8	162.1851	2093.2014	5/8	177.8931	2518.2992
3/4	162.5778	2103.3502	3/4	178.2858	2529.4297
7/8	162.9705	2113.5236	7/8	178.6785	2543.5849
52 in.	163.3632	2123.7216	57 in.	179.0712	2551.7646
1/8	163.7559	2133.9440	1/8	179.4639	2562.9688
1/4	164.1486	2144.1910	1/4	179.8566	2574.1975
3/8	164.5413	2154.4626	3/8	180.2493	2585.4509
1/2	164.9340	2164.7587	1/2	180.6423	2596.7287
5/8	165.3267	2175.0794	5/8	181.0347	2608.0311
3/4	165.7194	2185.4245	3/4	181.4274	2619.3580
7/8	166.1121	2195.7943	7/8	181.8201	2630.7095

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
58 in.	182.2128	2642.0856	63 in.	197.9208	3117.2526
1/8	182.6055	2653.4861	1/8	198.3135	3129.6349
1/4	182.9982	2664.9112	1/4	198.7062	3142.0417
3/8	183.3909	2676.3609	3/8	199.0989	3154.4732
1/2	183.7836	2687.8351	1/2	199.4916	3166.9291
5/8	184.1763	2699.3338	5/8	199.8843	3179.4096
3/4	184.5690	2710.8571	3/4	200.2770	3191.9146
7/8	184.9617	2722.4050	7/8	200.6697	3204.4442
59 in.	185.3544	2733.9774	64 in.	201.0624	3216.9984
1/8	185.7471	2745.5743	1/8	201.4551	3229.5770
1/4	186.1398	2757.1957	1/4	201.8478	3242.1782
3/8	186.5325	2768.8418	3/8	202.2405	3254.8080
1/2	186.9252	2780.5123	1/2	202.6332	3267.4603
5/8	187.3179	2792.2074	5/8	203.0259	3280.1372
3/4	187.7106	2803.9270	3/4	203.4186	3292.8385
7/8	188.1033	2815.6712	7/8	203.8113	3305.5645
60 in.	188.4960	2827.4400	65 in.	204.2040	3318.3151
1/8	188.8887	2839.2332	1/8	204.5917	3331.0900
1/4	189.2814	2851.0510	1/4	204.9894	3343.8875
3/8	189.6741	2862.8934	3/8	205.3821	3356.7137
1/2	190.0668	2874.7603	1/2	205.7748	3369.5623
5/8	190.4595	2886.6517	5/8	206.1675	3382.4355
3/4	190.8522	2898.5677	3/4	206.5602	3395.3332
7/8	191.2419	2910.5083	7/8	206.9529	3408.2555
61 in.	191.6376	2922.4734	66 in.	207.3456	3421.2024
1/8	192.0303	2934.4630	1/8	207.7383	3434.1737
1/4	192.4230	2946.4771	1/4	208.1310	3447.1676
3/8	192.8157	2958.5159	3/8	208.5237	3468.1901
1/2	193.2084	2970.5791	1/2	208.9164	3473.2351
5/8	193.6011	2982.6669	5/8	209.3091	3486.3047
3/4	193.9931	2994.7792	3/4	209.7018	3499.3987
7/8	194.3865	3006.9161	7/8	210.0945	3512.5174
62 in.	194.7792	3019.0776	67 in.	210.4872	3525.6606
1/8	195.1719	3031.2635	1/8	210.8799	3538.8283
1/4	195.5646	3043.4740	1/4	211.2726	3552.0185
3/8	195.9573	3055.7091	3/8	211.6653	3565.2374
1/2	196.3500	3067.9687	1/2	212.0580	3578.4787
5/8	196.7427	3080.2529	5/8	212.4507	3591.7446
3/4	197.1354	3092.5615	3/4	212.8434	3605.0350
7/8	197.5281	3104.8948	7/8	213.2361	3618.3300

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
68 in.	213.6288	3631.6896	73 in.	229.3368	4185.3966
1/8	214.0215	3645.0536	1/8	229.7295	4199.7424
1/4	214.4142	3658.4402	1/4	230.1222	4214.1107
3/8	214.8069	3671.8554	3/8	230.5149	4228.5077
1/2	215.1996	3685.2931	1/2	230.9076	4242.9271
5/8	215.5923	3698.7554	5/8	231.3003	4257.3711
3/4	215.9850	3712.2421	3/4	231.6930	4271.8396
7/8	216.3777	3725.7535	7/8	232.0857	4286.3327
69 in.	216.7704	3739.2894	74 in.	232.4784	4300.8504
1/8	217.1631	3752.8498	1/8	232.8711	4315.3926
1/4	217.5558	3766.4327	1/4	233.2638	4329.9572
3/8	217.9485	3780.0443	3/8	233.6565	4344.5505
1/2	218.3412	3793.6783	1/2	234.0492	4359.1663
5/8	218.7339	3807.3369	5/8	234.4419	4373.8067
3/4	219.1266	3821.0200	3/4	234.8346	4388.4715
7/8	219.5193	3834.7277	7/8	235.2273	4403.1610
70 in.	219.9120	3848.4600	75 in.	235.6200	4417.8750
1/8	220.3047	3862.2167	1/8	236.0127	4432.6135
1/4	220.6974	3875.9960	1/4	236.4054	4447.3745
3/8	221.0901	3889.8039	3/8	236.7981	4462.1642
1/2	221.4828	3903.6343	1/2	237.1908	4476.9763
5/8	221.8755	3917.4893	5/8	237.5835	4491.8130
3/4	222.2682	3931.3687	3/4	237.9762	4506.6742
7/8	222.6609	3945.2728	7/8	238.3689	4521.5600
71 in.	223.0536	3959.2014	76 in.	238.7616	4536.4704
1/8	223.4463	3973.1545	1/8	239.1543	4551.4023
1/4	223.8390	3987.1301	1/4	239.5470	4566.3626
3/8	224.2317	4001.1344	3/8	239.9397	4581.3486
1/2	224.6244	4015.1611	1/2	240.3324	4596.3571
5/8	225.0171	4029.2124	5/8	240.7251	4611.3902
3/4	225.4098	4043.2882	3/4	241.1178	4626.4477
7/8	225.8025	4057.3886	7/8	241.5105	4641.5299
72 in.	226.1952	4071.5136	77 in.	241.9032	4656.6366
1/8	226.5879	4085.6631	1/8	242.2959	4671.7678
1/4	226.9806	4099.8350	1/4	242.6886	4686.9215
3/8	227.3733	4114.0356	3/8	243.0813	4702.1039
1/2	227.7660	4128.2587	1/2	243.4740	4717.3087
5/8	228.1587	4142.5064	5/8	243.8667	4732.5381
3/4	228.5514	4156.7785	3/4	244.2594	4747.7920
7/8	228.9441	4171.0753	7/8	244.6521	4763.0705

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
78 in.	245.0448	4778.3736	83 in.	260.7528	5410.6206
1/8	245.4375	4793.7012	1/8	261.1455	5426.9299
1/4	245.8302	4809.0512	1/4	261.5382	5443.2617
3/8	246.2229	4824.4299	3/8	261.9309	5459.6222
1/2	246.6156	4839.8311	1/2	262.3236	5476.0051
5/8	247.0083	4855.2568	5/8	262.7163	5492.4118
3/4	247.4010	4870.7071	3/4	263.1090	5508.8446
7/8	247.7937	4886.1820	7/8	263.5017	5525.3012
79 in.	248.1864	4901.6814	84 in.	263.8944	5541.7824
1/8	248.5791	4917.2053	1/8	264.2871	5558.2881
1/4	248.9718	4932.7517	1/4	264.6798	5574.8162
3/8	249.3645	4948.3268	3/8	265.0725	5591.3730
1/2	249.7572	4963.9243	1/2	265.4652	5607.9523
5/8	250.1499	4979.5456	5/8	265.8579	5624.5554
3/4	250.5426	4995.1930	3/4	266.2506	5641.1845
7/8	250.9353	5010.8642	7/8	266.6433	5657.8357
80 in.	251.3280	5026.5600	85 in.	267.0360	5674.5150
1/8	251.7207	5042.2803	1/8	267.4287	5691.2170
1/4	252.1134	5058.0230	1/4	267.8214	5707.9415
3/8	252.5061	5073.7944	3/8	268.2141	5724.6947
1/2	252.8988	5089.5883	1/2	268.6068	5741.4703
5/8	253.2915	5106.4060	5/8	268.9997	5758.2697
3/4	253.6842	5121.2497	3/4	269.3922	5775.0952
7/8	254.0769	5137.1173	7/8	269.7849	5791.9445
81 in.	254.4696	5153.0094	86 in.	270.1776	5808.8184
1/8	254.8623	5168.9260	1/8	270.5703	5825.7168
1/4	255.2550	5184.8651	1/4	270.9630	5842.6376
3/8	255.6477	5200.8329	3/8	271.3557	5859.5871
1/2	256.0404	5216.8231	1/2	271.7484	5876.5591
5/8	256.4331	5232.8371	5/8	272.1411	5893.5549
3/4	256.8258	5248.8772	3/4	272.5338	5910.5767
7/8	257.2105	5264.9411	7/8	272.9265	5927.6224
82 in.	257.6112	5281.0296	87 in.	273.3192	5944.6926
1/8	258.0039	5297.1426	1/8	273.7119	5961.7873
1/4	258.3966	5313.2780	1/4	274.1046	5978.9045
3/8	258.7893	5329.4421	3/8	274.4973	5996.0504
1/2	259.1820	5345.6287	1/2	274.8900	6013.2187
5/8	259.5747	5361.8391	5/8	275.2827	6030.4108
3/4	259.9674	5378.0755	3/4	275.6754	6047.6290
7/8	260.3601	5394.3358	7/8	276.0681	6064.8710

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
88 in.	276.4608	6082.1376	93 in.	292.1688	6792.9248
1/8	276.8535	6099.4287	1/8	292.5615	6811.1974
1/4	277.2462	6116.7422	1/4	292.9542	6829.4927
3/8	277.6389	6134.0844	3/8	293.3469	6847.8167
1/2	278.0316	6151.4491	1/2	293.7396	6866.1631
5/8	278.4243	6169.8376	5/8	294.1323	6884.5338
3/4	278.8170	6186.2591	3/4	294.5350	6902.9296
7/8	279.2097	6203.6905	7/8	294.9177	6921.3497
89 in.	279.6024	6221.1534	94 in.	295.3104	6939.7946
1/8	279.9951	6238.6408	1/8	295.7031	6958.2636
1/4	280.3878	6256.1507	1/4	296.0958	6976.7552
3/8	280.7805	6273.6893	3/8	296.4885	6995.2755
1/2	281.1732	6291.2503	1/2	296.8812	7013.8183
5/8	281.5659	6308.8351	5/8	297.2739	7032.3853
3/4	281.9586	6326.4460	3/4	297.6666	7050.9775
7/8	282.3513	6344.0807	7/8	298.0593	7069.5940
90 in.	282.7440	6361.7400	95 in.	298.4520	7088.2352
1/8	283.1367	6379.4238	1/8	298.8447	7106.9005
1/4	283.5294	6397.1300	1/4	299.2374	7125.5885
3/8	283.9221	6414.8649	3/8	299.6301	7144.3052
1/2	284.3148	6432.6223	1/2	300.0228	7163.0443
5/8	284.7075	6450.4039	5/8	300.4155	7181.8077
3/4	285.1002	6468.2107	3/4	300.8082	7200.5962
7/8	285.4929	6486.0418	7/8	301.2009	7219.4090
91 in.	285.8856	6503.8974	96 in.	301.5936	7238.2466
1/8	286.2783	6521.7772	1/8	301.9863	7257.1083
1/4	286.6710	6539.6801	1/4	302.3790	7275.9926
3/8	287.0637	6557.6114	3/8	302.7717	7294.9056
1/2	287.4564	6573.5651	1/2	303.1644	7313.8411
5/8	287.8491	6593.5431	5/8	303.5571	7332.8008
3/4	288.2418	6611.5462	3/4	303.9498	7351.7857
7/8	288.6345	6629.5736	7/8	304.3425	7370.7949
92 in.	289.0272	6647.6258	97 in.	304.7352	7389.8288
1/8	289.4199	6665.7021	1/8	305.1279	7408.8868
1/4	289.8125	6683.8010	1/4	305.5206	7427.9675
3/8	290.2053	6701.9286	3/8	305.9133	7447.0769
1/2	290.5980	6720.0787	1/2	306.3060	7466.2087
5/8	290.9907	6738.2530	5/8	306.6987	7485.3648
3/4	291.3834	6756.4525	3/4	307.0914	7504.5460
7/8	291.7661	6774.6763	7/8	307.4841	7523.7515

XXVIII.

Diameter.	Circum.	Area.	Diameter.	Circum.	Area.
98 in.	307.8768	7542.9818	1/32	311.4111	7717.1563
1/32	308.2695	7562.2362	1/16	311.8038	7736.6297
1/16	308.6622	7581.5132	3/32	312.1965	7756.1318
3/32	309.0549	7600.8189	1/8	312.5892	7775.6563
1/8	309.4476	7620.1471	5/32	312.9819	7795.2051
5/32	309.8403	7639.4995	3/16	313.3746	7814.7790
3/16	310.2330	7658.8771	7/32	313.7673	7834.3772
7/32	310.6257	7678.2790			
			100 in.	314.1600	7854.0000
99 in.	311.0184	7697.7056			

A TABLE CONTAINING
THE CIRCUMFERENCES AND AREAS
OF CIRCLES,

From 8 to 30 Feet, advancing by an Inch at a time.

Diameter in Feet and Inches.	Circumference in Feet and Inches.		Area in Feet.	Diameter in Feet and Inches.	Circumference in Feet and Inches.		Area in Feet.
8 ft.	25	$1\frac{1}{2}$	50.2656	5	32	$8\frac{5}{8}$	85.2211
1	25	$4\frac{5}{8}$	51.3178	6	32	$11\frac{3}{4}$	86.5903
2	25	$7\frac{7}{8}$	52.3816	7	33	$2\frac{7}{8}$	87.9697
3	25	11	53.4562	8	33	$6\frac{1}{8}$	89.3608
4	26	$2\frac{1}{8}$	54.5412	9	33	$9\frac{1}{4}$	90.7627
5	26	$5\frac{1}{4}$	55.6377	10	34	$0\frac{3}{8}$	92.1749
6	26	$8\frac{3}{8}$	56.7451	11	34	$3\frac{1}{2}$	93.5986
7	26	$11\frac{1}{2}$	57.8628				
8	27	$2\frac{3}{4}$	58.9920	11 ft.	34	$6\frac{5}{8}$	95.0334
9	27	$5\frac{3}{4}$	60.1321	1	34	$9\frac{3}{4}$	96.4783
10	27	9	61.2826	2	35	$0\frac{7}{8}$	97.9347
11	28	$0\frac{1}{8}$	62.4445	3	35	$4\frac{1}{8}$	99.4021
				4	35	$7\frac{1}{4}$	100.8797
9 ft.	28	$3\frac{1}{4}$	63.6174	5	35	$10\frac{5}{8}$	102.3689
1	28	$6\frac{3}{8}$	64.8006	6	36	$1\frac{1}{2}$	103.8691
2	28	$9\frac{1}{2}$	65.9951	7	36	$4\frac{5}{8}$	105.3794
3	29	$0\frac{5}{8}$	67.2007	8	36	$7\frac{3}{4}$	106.9013
4	29	$3\frac{3}{4}$	68.4166	9	36	$10\frac{7}{8}$	108.4342
5	29	7	69.6440	10	37	$2\frac{3}{4}$	109.9772
6	29	$10\frac{1}{8}$	70.8823	11	37	$5\frac{1}{4}$	111.5319
7	30	$1\frac{1}{4}$	72.1309				
8	30	$4\frac{3}{8}$	73.3910	12 ft.	37	$8\frac{3}{8}$	113.0976
9	30	$7\frac{1}{2}$	74.6620	1	37	$11\frac{1}{2}$	114.6732
10	30	$11\frac{5}{8}$	75.9433	2	38	$2\frac{5}{8}$	116.2607
11	31	$1\frac{3}{4}$	76.2362	3	38	$5\frac{3}{4}$	117.8590
				4	38	$8\frac{7}{8}$	119.4674
10 ft.	31	5	78.5400	5	39	0	121.0876
1	31	$8\frac{1}{8}$	79.8540	6	39	$3\frac{1}{4}$	122.7187
2	31	$11\frac{1}{4}$	81.1795	7	39	$6\frac{3}{8}$	124.3598
3	32	$2\frac{3}{8}$	82.5160	8	39	$9\frac{1}{2}$	126.0127
4	32	$5\frac{1}{2}$	83.8627	9	40	$0\frac{5}{8}$	127.6765

Diameter in Feet and Inches.	Circumference in Feet and Inches.	Area in Feet.	Diameter in Feet and Inches.	Circumference in Feet and Inches.	Area in Feet.
10	40 3¾	129.3504	2	50 9⅝	205.2726
11	40 6⅞	131.0360	3	51 0½	207.3946
			4	51 3¾	209.5264
13 ft.	40 10	132.7326	5	51 6½	211.6703
1	41 1⅛	134.4391	6	51 10	213.8251
2	41 4⅜	136.1574	7	52 1½	215.9896
3	41 7½	137.8867	8	52 4¼	218.1662
4	41 10⅝	139.6260	9	52 7⅜	220.3537
5	42 1⅝	141.3771	10	52 10½	222.5510
6	42 4⅞	143.1391	11	53 1⅝	224.7603
7	42 8	144.9111			
8	42 11⅛	146.6949	17 ft.	53 4⅞	226.9806
9	43 2¼	148.4896	1	53 8	229.2105
10	43 5⅛	150.2943	2	53 11⅛	231.4525
11	43 8⅝	152.1109	3	54 2⅛	233.7055
			4	54 5⅜	235.9682
14 ft.	43 11¾	153.9384	5	54 8½	238.2430
1	44 2⅞	155.7758	6	54 11⅝	240.5287
2	44 6	157.6250	7	55 2⅞	242.8241
3	44 9⅛	159.4852	8	55 6	245.1316
4	45 0¼	161.3553	9	55 9⅛	247.4500
5	45 3½	163.2373	10	56 0¼	249.7781
6	45 6⅝	165.1303	11	56 3½	252.1184
7	45 9¾	167.0331			
8	46 0⅞	168.9479	18 ft.	56 6½	254.4696
9	46 4	170.8735	1	56 9⅝	256.8303
10	46 7⅛	172.8091	2	57 0⅞	259.2033
11	46 11¼	174.7565	3	57 4	261.5872
			4	57 7⅛	263.9807
15 ft.	47 1½	176.7150	5	57 10¼	266.3864
1	47 4⅝	178.6832	6	58 1⅜	268.8031
2	47 7¾	180.6634	7	58 4½	271.2293
3	47 10⅞	182.6515	8	58 7⅝	273.6678
4	48 2½	184.6555	9	58 10¾	276.1171
5	48 5⅛	186.6684	10	59 2	278.5761
6	48 8¼	188.6923	11	59 5⅛	281.0472
7	48 11⅜	190.7260			
8	49 2⅝	192.7716	19 ft.	59 8¼	283.5294
9	49 5¾	194.8282	1	59 11½	286.0210
10	49 8⅞	196.8946	2	60 2½	288.5249
11	50 0	198.9730	3	60 5⅝	291.0397
			4	60 8¾	293.5641
16 ft.	50 3⅛	201.0624	5	60 11⅞	296.1107
1	50 6¼	203.1615	6	61 3⅛	298.6483

Diameter in Feet and Inches.	Circumference in Feet and Inches.	Area in Feet.	Diameter in Feet and Inches.	Circumference in Feet and Inches.	Area in Feet.
7	61 6¼	301.2054	23 ft.	72 3	415.4766
8	61 9½	303.7747	1	72 6⅛	418.4915
9	62 0⅛	306.3550	2	72 9⅜	421.5192
10	62 3⅝	308.9448	3	73 0½	424.5577
11	62 6¾	311.5469	4	73 3⅝	427.6055
			5	73 6¾	430.6658
20 ft.	62 9⅞	314.1600	6	73 9⅞	433.7371
1	63 1⅛	316.7824	7	74 1	436.8175
2	63 4¼	319.4173	8	74 4⅛	439.9106
3	63 7⅜	322.0630	9	74 7¼	443.0146
4	63 11½	324.7182	10	74 10⅜	446.1278
5	64 1⅝	327.3858	11	75 1⅝	449.2536
6	64 4¾	330.0643			
7	64 7⅞	332.7522	24 ft.	75 4¾	452.3904
8	64 11	335.4525	1	75 7⅞	455.5362
9	65 2¼	338.1637	2	75 11	458.6948
10	65 5⅜	340.8844	3	76 2⅛	461.8642
11	65 8¼	343.6174	4	76 5¼	465.0428
			5	76 8½	468.2341
21 ft.	65 11⅝	346.3614	6	76 11⅝	471.4363
1	66 2¾	349.1147	7	77 2¾	474.6476
2	66 5⅞	351.8804	8	77 5⅞	477.8716
3	66 9	354.6571	9	77 9	481.1065
4	67 0⅛	357.4432	10	78 0⅛	484.3506
5	67 3⅜	360.2417	11	78 3¼	487.6073
6	67 6½	363.0511			
7	67 9⅝	365.8698	25 ft.	78 6⅜	490.8750
8	68 0¾	368.7011	1	78 9½	494.1516
9	68 3⅞	371.5432	2	79 0¾	497.4411
10	68 7	374.3947	3	79 3⅞	500.7415
11	68 10¼	377.2587	4	79 7⅛	504.0510
			5	79 11½	507.3732
22 ft.	69 1⅜	380.1336	6	84 1¼	510.7063
1	69 4½	383.0177	7	80 4⅝	514.0484
2	69 7⅝	385.9144	8	80 7⅝	517.4034
3	69 10¾	388.8220	9	80 10¾	520.7692
4	70 1⅞	391.7389	10	81 1⅞	524.1441
5	70 5	394.6683	11	81 5	527.5318
6	70 8¼	397.6087			
7	70 11⅛	400.5583	26 ft.	81 8⅛	530.9304
8	71 2½	403.5204	1	81 11¼	534.3379
9	71 5⅝	406.4935	2	82 2⅜	537.7583
10	71 8¾	409.4759	3	82 5¼	541.1896
11	71 11⅞	412.4707	4	82 8⅝	541.6299

Diameter in Feet and Inches.	Circumference in Feet and Inches.	Area in Feet.	Diameter in Feet and Inches.	Circumference in Feet and Inches.	Area in Feet.
5	82 11⅞	548.0830	3	88 9	626.7982
6	83 3	551.5471	4	89 0½	630.5002
7	83 6½	555.0201	5	89 3¼	634.2152
8	83 9¼	558.5059	6	89 6⅜	637.9411
9	84 0⅜	562.0027	7	89 9½	641.6758
10	84 3½	565.5084	8	90 0⅝	645.4235
11	84 6⅝	569.0270	9	90 3¾	649.1821
			10	90 6⅞	652.9495
27 ft.	84 9⅞	572.5566	11	90 11⅛	656.7300
1	85 1	576.0949			
2	85 4¼	579.6463	29 ft.	91 1¼	660.5214
3	85 8⅛	583.2085	1	91 4⅜	664.3214
4	85 11⅜	586.7796	2	91 7½	668.1346
5	86 1½	590.3637	3	91 10⅝	671.9587
6	86 4⅝	593.9587	4	92 1¾	675.7915
7	86 7⅞	597.5625	5	92 4⅞	679.6375
8	86 11	601.1793	6	92 8⅛	683.4943
9	87 2⅛	604.8070	7	92 11⅛	687.3598
10	87 5¼	608.4436	8	93 2⅜	691.2385
11	87 8⅜	612.0931	9	93 5½	695.1280
			10	93 8⅝	699.0263
28 ft.	87 11½	615.7536	11	93 11⅞	702.9377
1	88 2⅝	619.4228			
2	88 5¾	623.1050	30 ft.	94 2⅞	706.8600

XXXIII.

A TABLE:

Shewing the Pressure of Steam, from $2\frac{1}{2}$lbs up to 60lbs; and the height of a Column of Mercury, and the number of Feet and Inches of Water in a Column at the different Pressures.

Pressure of Steam.	Inches of Mercury Column.	Feet and Inches of Water in height at the Temperature and Pressure.	
Pounds.	Inches.	Feet.	Inches.
$2\frac{1}{2}$	5·15	5	9
3	6·18	6	11
$3\frac{1}{2}$	7·21	8	$0\frac{3}{4}$
4	8·24	9	$2\frac{1}{4}$
$4\frac{1}{2}$	9·27	10	4
5	10·30	11	6
$5\frac{1}{2}$	11·33	12	8
6	12·36	13	10
$6\frac{1}{2}$	13·39	15	0
7	14·42	16	2
$7\frac{1}{2}$	15·45	17	$4\frac{1}{2}$
8	16·48	18	5
10	20·60	23	$0\frac{1}{2}$
12	24·72	27	8
15	39·90	34	6
20	41·20	46	$1\frac{1}{4}$
25	51·50	57	$7\frac{1}{2}$
30	61·80	69	$1\frac{1}{2}$
35	72·12	86	8
40	82·41	92	$2\frac{1}{2}$
45	92·70	103	9
50	103·00	115	3
55	113·31	126	9
60	123·60	138	$3\frac{1}{2}$
Additional column of 2·037 inches of Mercury for each extra pound pressure.		2 feet $3\frac{1}{4}$ inches of a column extra for each increased pound pressure.	

Steam produced from impure water is not of equal density to steam from pure water. Steam from pure water, at a temperature of 212 degrees, supports a column of mercury of 30 inches; and steam from sea water, at the same temperature, supports only $22\frac{3}{4}$ inches. Common water, at a temperature of 220 degrees, supports 35 inches; and sea water, at the same temperature, $26\frac{1}{2}$ inches of a column of mercury. Pressure and temperature in this case varies. In all cases where accuracy of pressure is requisite, an open column of mercury is the most sensitive and correct indicator.

XXXIV.

A TABLE:

Shewing the Temperature of Steam at different Pressures, from 1lb per Square Inch to 240lbs, and the quantity of Steam produced from a Cubic Inch of Water, according to Pressure.

NOTE.—Add the pressure of the atmosphere, 15lbs, to the pressure on the steam gauge, to correspond with the table.

Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.	Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.
1	102·9	20868	32	255·5	833
2	126·1	10874	33	257·3	810
3	141·0	7437	34	259·1	788
4	152·3	5685	35	260·9	767
5	161·4	4617	36	262·6	748
6	169·2	3897	37	264·3	729
7	175·9	3376	38	265·9	712
8	182·0	2983	39	267·5	695
9	187·4	2674	40	269·1	679
10	192·4	2426	41	270·6	664
11	197·0	2221	42	272·1	649
12	201·3	2050	43	273·6	635
13	205·3	1904	44	275·0	622
14	209.1	1778	45	276·4	610
15 Pressr. of Atmsphr.	212·8	1669	46	277.8	598
16	216·3	1573	47	279·2	586
17	219·6	1488	48	280·5	575
18	222·7	1411	49	281·9	564
19	225·6	1343	50	283·2	554
20	228·5	1281	51	284·4	544
21	231·2	1225	52	285·7	534
22	233·8	1174	53	286·9	525
23	236·3	1127	54	288·1	516
24	238·7	1084	55	289·3	508
25	241·0	1044	56	290·5	500
26	243·3	1007	57	291·7	492
27	245·5	973	58	292·9	484
28	247·6	941	59	294·2	477
29	249·6	911	60	295·6	470
30	251·6	883	61	296·9	463
31	253·6	857	62	298·1	456

Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.	Total Pressure of Steam in lbs per Square Inch.	Corresponding Temperature of Steam to Pressure.	Cubic Inches of Steam from a Cubic Inch of Water according to Pressure.
63	299·2	449	89	323·5	328
64	300·3	443	90	324·3	325
65	301·3	437	91	325·1	322
66	302·4	431	92	325·9	319
67	303·4	425	93	326·7	316
68	304·4	419	94	327·5	313
69	305·4	414	95	328·2	310
70	306·4	408	96	329·0	307
71	307·4	403	97	329·8	304
72	308·4	398	98	330·5	301
73	309·3	393	99	331·3	298
74	310·3	388	100	332·0	295
75	311·2	383	110	339·2	271
76	312·2	379	120	345·8	251
77	313·1	374	130	352·1	233
78	314·0	370	140	357·9	218
79	314·9	366	150	363·4	205
80	315·8	362	160	368·7	183
81	316·7	358	170	373·6	193
82	317·6	354	180	378·4	174
83	318·4	350	190	382·9	166
84	319·3	346	200	387·3	158
85	320·1	342	210	391·5	151
86	321·0	339	220	395·5	145
87	321·8	335	230	399·4	140
88	322·6	332	240	403·1	134

This table shews that the saving of fuel is in proportion to the increase of pressure. The advantage of generating and using high-pressure steam is thereby made apparent. The table shews that the last 10lbs of additional pressure only requires 4 degrees of heat to raise it; whereas the first 10lbs of pressure above the atmosphere requires 29 additional degrees of heat to raise it—a difference of 25 degrees. Hence a small accession of heat at a high temperature, produces an increase of elastic force; and a small abstraction of heat reduces its bulk, by the application of cold, in the ratio of its density; proving the advantage of clothing cylinders, steam pipes, boilers, &c., with a non-conductor of heat or cold—a sure saving of fuel where adopted, and more particularly required where high-pressure steam is used.

XXXVI.

A TABLE:

SHEWING THE WEIGHT OF WATER IN PIPES OF VARIOUS DIAMETERS, ONE FOOT IN LENGTH.

Diameter in Inches.	Weight in Pounds.	Diameter in Inches.	Weight in Pounds.	Diameter in Inches.	Weight in Pounds.
3	3	12¼	51	23	180¼
3¼	3½	12½	53¼	23½	188¼
3½	4¼	12¾	55½	24	196¼
3¾	4¾	13	57½	24½	204½
4	5½	13¼	59¾	25	213
4¼	6¼	13½	62¼	25½	221½
4½	7	13¾	64½	26	230½
4¾	7¾	14	66¾	26½	239½
5	8½	14¼	69¼	27	248½
5¼	9¼	14½	71½	27½	257¾
5½	10¼	14¾	74¼	28	267¼
5¾	11¼	15	76¾	28½	276¾
6	12¼	15¼	79¼	29	286½
6¼	13¼	15½	82	29½	296½
6½	14½	15¾	84½	30	306¾
6¾	15½	16	87¼	30½	317¼
7	16¾	16¼	90	31	327½
7¼	18	16½	92¾	31½	338¼
7½	19¼	16¾	95½	32	349
7¾	20½	17	98½	32½	360
8	21¾	17¼	101½	33	371¼
8¼	23¼	17½	104½	33½	382½
8½	24½	17¾	107½	34	394
8¾	26	18	110½	34½	405¾
9	27½	18¼	113½	35	417½
9¼	29¼	18½	116½	35½	429½
9½	30¾	18¾	119¾	36	441¾
9¾	32½	19	123	36½	454
10	34	19¼	126¼	37	466½
10¼	35½	19½	129½	37½	479¼
10½	37½	19¾	132	38	492¼
10¾	39¼	20	136¼	38½	505¼
11	41¼	20½	143¼	39	518½
11¼	43¼	21	150¼	39½	531¾
11½	45	21½	157½	40	545½
11¾	47	22	165		
12	49	22½	172½		

A TABLE:

SHEWING THE WEIGHT CYLINDRICAL COLUMNS OF CAST-IRON WILL BEAR WITH SAFETY, BY TREDGOLD.

Length of Column in feet	2	4	6	8	10	12	14	16	18	20	22	24
Dia. in Ins.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.	Cwt.
1	18	12	8	5	3	2	2	1	1	1		
CWT. THE COLUMN WILL BEAR.												
1½	44	36	28	19	16	12	9	7	6	5	4	3
2	82	72	60	49	40	32	26	22	18	15	13	11
2½	129	119	105	91	77	65	55	47	40	34	28	25
3	188	178	163	145	128	111	97	84	73	64	56	49
3½	257	247	232	214	191	172	156	135	119	106	94	83
4	337	326	310	288	266	242	220	198	178	160	144	130
4½	429	418	400	379	354	327	301	275	251	229	208	189
5	530	522	501	479	452	427	394	363	337	310	285	262
6	616	607	592	573	550	525	497	469	440	413	386	360
7	1040	1032	1013	989	959	924	887	848	808	765	725	686
8	1344	1333	1315	1289	1259	1224	1185	1142	1097	1052	1005	959
9	1727	1716	1697	1672	1640	1603	1561	1515	1467	1416	1364	1311
10	2133	2122	2113	2077	2045	2007	1964	1916	1865	1811	1755	1697
11	2580	2570	2550	2520	2490	2450	2410	2380	2320	2250	2190	2130
12	3074	3050	3040	3020	2970	2930	2900	2830	2780	2730	2670	2600

XXXVIII.

DURABLE CEMENT

FOR STEAM AND WATER JOINTS, GAS RETORTS, ETC.

Take 10lbs of Ground Litharge, 4lbs of Ground Paris White, ½lb of Yellow Ochre, 2lbs of Red Lead, ½oz. of Hemp, cut into lengths of half-an-inch. Mix all together with Boiled Linseed Oil, to the consistence of very stiff Putty. Make the joint with the Cement in the usual way. The above mixture, well made, will set quickly when heat is applied. It answers well for the joints of steam pipes, for leakages in boilers, for cisterns, gas retorts, or any other purpose requiring a durable Cement. It resists fire, and will set in water.

See that the whole is well ground and mixed together.

Be particular that the Litharge is good. It is too often adulterated by the retail dealers.

Since this receipt was published in the first edition of this work, several parties make and vend the Cement, but of a very inferior quality —the greatest portion of the ingredients being Bristol Brick and Sea Sand, with a little Litharge.

The Cement may be had, mixed, of Messrs. HOPKINSON AND Co., Britannia Works, Huddersfield, in Casks, at 42/- per cwt.

USEFUL CEMENT

FOR RESERVOIRS, CISTERNS, WALLS, WATER COURSES, ETC.

Take 90 parts of well-burnt Brick or Clay (Fire Brick is the best), and 10 parts of Litharge, well pulverised and mixed together with Boiled Linseed Oil, to the consistency of thin plaster.

Use it in the same manner as plaster, previously wetting the parts to be covered with water. This last precaution is indispensable, or the Oil will be absorbed, and prevent the Cement from hardening. Applied in the mode stated, in three or four days the Cement will become firm.

GLOSSARY.

MP.—A pump to withdraw the condensed steam and water from the condenser of the Steam Engine.

T.—The lower part of the furnace, under the fire bars.

HERIC SINGLE-ACTING ENGINE.—The pressure of the steam acts during the up-stroke only; the return-stroke being performed by the pressure of the atmosphere, when a partial vacuum is formed under the piston by the application of cold water.

LASH.—The term given to jars, when one portion of the machinery has its velocity so increased from some cause that it rebounds with a sudden blow upon the parts from which it ought to derive its motion.

WING-OFF.—Ejecting water from the bottom of the boiler in order to prevent the deposition of scale, or mud.

W-THROUGH VALVE.—A valve to blow steam through the cylinder and condenser before starting.

L.—A disc of cast-iron. An irregular figure for giving motion to the expansion-valve.

THING THE STEAM PIPE, BOILER, &C.—Covering them with felt, or other non-conducting materials.

IPOUND SAFETY VALVE—discharges the steam when the water gets too low in the boiler, or the steam too high.—Hopkinson's Patent.

DENSING ENGINE.—In which the steam is condensed after leaving the cylinder, thus forming a vacuum on one side of the piston.

NTER.—An instrument for registering the strokes of an Engine, or the speed of other machines.

ER, OR LAP, OF THE SLIDE VALVE—is an extra breadth of the valve-face on the [illegible] for the purpose of cutting off the steam before the [illegible] of the stroke, so as to work expansively.

CLOSING OF THE EXHAUST—may be either late or early. Early closing is when the valve closes the exhaust-port before the termination of the stroke; the piston is then cushioned by the elasticity of the steam betwixt the top or bottom of the cylinder.

DIAGRAM OF INDICATOR.—A figure traced by the pencil of the Steam Engine Indicator.

DIRECT-ACTING ENGINE.—An Engine in which the piston communicates in a direct manner from the piston-rod to the crank.

DONKEY ENGINE.—An auxiliary for feeding the boilers, or for other purposes requiring power.

DOUBLE-ACTING ENGINE is one in which the steam acts on each side of the piston alternately, with or without a vacuum.

DOUBLE-ACTING PUMP.—One which lifts and forces alternately.

ECCENTRIC.—Used for giving the proper stroke to the valves.

EDUCTION OR EXHAUST-PORTS.—Through which the steam passes from the valves to the condenser, or to the atmosphere.

EFFECTIVE HEATING SURFACE IN A BOILER.—Half or upper side of the flue in a Cornish boiler, or half the surface in tubular boilers.

ENGINEER OR ENGINE-TENTER.—The manager of an Engine.

EQUILIBRIUM, CORNISH, OR DOUBLE-BEAT VALVES.—Valves which are pressed by steam in all directions.

EXPANSION GEAR.—Worked independently of the cylinder-valves for the purpose of cutting off the steam at different portions of the stroke.

FOOT VALVE.—A valve between the bottom of the condenser and the air-pump.

FUSIBLE PLUGS.—Fusible metal plugs fitted in boilers, being *expected* to melt when the boiler becomes short of water, or the temperature too high.

GAUGE COCKS.—Attached to boilers, and *supposed* to indicate the level of the water.

GLASS WATER GAUGE.—A glass tube, one end being connected to the water and the other to the steam portion of the boiler, for shewing the level of the water therein.

GOVERNOR.—For regulating the speed of the Engine.

HIGH-PRESSURE.—Non-condensing Engines.

HIGH-PRESSURE STEAM.—Steam 20lbs, or more, above the pressure of the atmosphere.

HORSE POWER, nominal or indicated, is 33,000lbs weight raised one foot high per minute, independently of the friction of the Engine and shafting.

INCRUSTATION, OR SCALE.—Ingredients which collect on the inner surface of the plates of a boiler.

INDICATOR.—An instrument used for ascertaining the working condition of an Engine, or the power it is exerting.

INJECTION.—A jet of cold water used to condense the steam in the condenser.

LEAD OF SLIDE VALVE.—Opening of the valve to admit the steam to the opposite side of the piston, before the termination of the stroke.

LUBRICATOR.—A cup for holding oil or tallow, and distributing it to the working parts in the interior of the cylinder, or to rubbing surfaces.

OSCILLATING ENGINE.—An Engine in which the cylinders oscillate; the head of the piston-rod being attached to the crank-pin.

SAFETY VALVES.—Valves attached to boilers for the escape of steam when it has obtained its maximum.

STEAM ROOM.—Space for steam above the water in the boiler, or in the pipes or passages to the Engine.

STEAM GAUGE.—To shew the pressure of the steam in the boiler.

STOP VALVES.—Valves betwixt the boiler and Engine.

SUPER-HEATED STEAM.—Steam the temperature of which has been increased after leaving the boiler.

SURCHARGED STEAM.—Steam which has an excess of watery particles held in mechanical suspension.

THROTTLE VALVE.—A valve to regulate the flow of the steam from the boiler to the Engine.

TUBULAR BOILER.—A boiler having a great number of tubes, through which the flame passes into the chimney after leaving the furnace.

VACUUM GAUGE.—Connected with the condenser, to shew the amount of vacuum.

VALVE CASING.—A covering for the valve containing the steam.

WASTE STEAM.—Steam from a High-pressure or Non-condensing Engine after leaving the cylinder.

B. BROWN, PRINTER, MARKET-PLACE-CORNER, HUDDERSFIELD.

ADVERTISEMENTS

OF

USEFUL ADJUNCTS

FOR

STEAM ENGINES AND BOILERS,

MANUFACTURED BY

J. HOPKINSON & Co.,

ENGINEERS, HUDDERSFIELD.

Mr. Hopkinson attends Manchester Royal Exchange on Tuesdays.

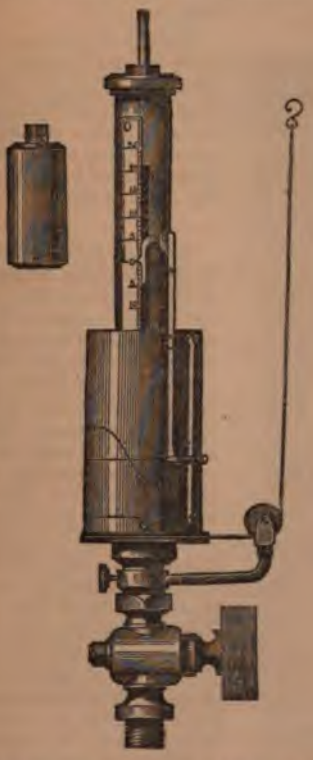
IMPROVED

EAM ENGINE INDICATOR,

FOR HIGH AND LOW PRESSURE.

OPKINSON & CO., BRITANNIA WORKS, HUDDERSFIELD.

STEAM ENGINE INDICATORS
ALTERED, REPAIRED, AND ADJUSTED.



CONSTRUCTED FOR ANY PRESSURE REQUIRED.

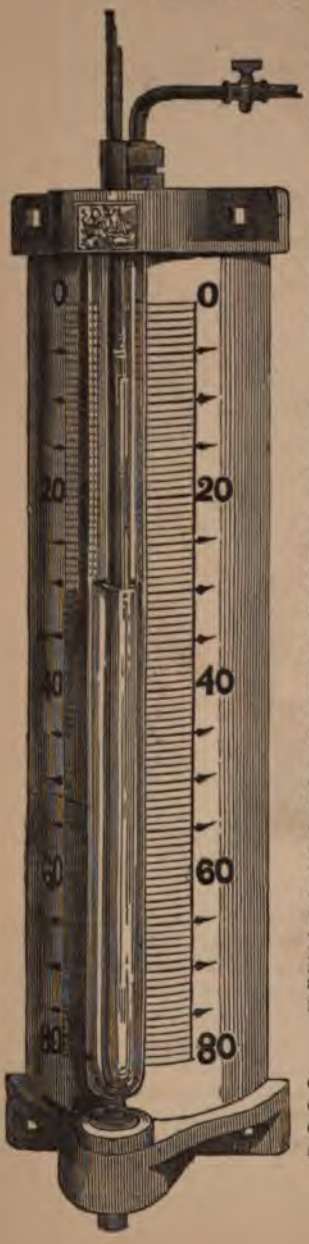
Indicator the Pencil is parallel with the Cylinder and Piston of the Instrument, parts are so accurately fitted together, and of the requisite strength to resist strain, operation of the Pencil on the paper is descriptive of the actual working of the nd the beating of the Valves. The Diagrams furnished by the Instrument may on—the indication being accurate ; defects, from whatever cause, being regis- nd also [illegible] tion which may be made in the working parts of the Engine. introd[illegible] this Indicator [illegible] recent progress in the art of "Valve-Setting" has de by [illegible] the circumstance of its faithfully describing tion[illegible] ars. HOPKINSONS' make are more sensitive [illegible] large diagram that may be easily read.

MESSRS. HOPKINSON & CO.

Beg to call attention to their PATENTED

MERCURIAL STEAM GAUGE,

Upwards of 2,000 of which are now in use.



For simplicity of construction, certainty of action, and accuracy of indication, it is far superior to any Gauge yet introduced, and will be as efficient at the end of twenty years as at the commencement.

A column of Mercury, as the truest Indicator of the pressure of Steam, was first adopted by that great improver of the Steam Engine, JAMES WATT; and for the Low-pressure Boilers of his time, the simple Mercurial Syphon which he introduced was most efficient as an Indicator, and best adapted for the wants of the times.

Since the days of WATT, however, the use of High-pressure Steam has been continually on the increase, because of its great economy; and to High-pressure Boilers the Low-pressure Syphon Gauge is inapplicable; and though attempts have been made to adapt the open column of Mercury (which all admit is the most perfect indicator of pressure) to the new circumstances, still the inconvenient length of scale which the indication of high-pressure requires, has prevented the use of Instruments upon this arrangement. In the Patented Mercurial Gauge, however, Messrs. HOPKINSON have surmounted this hitherto formidable difficulty. While their Gauge is formed by the direct action of an open column of Mercury, the Registering Apparatus is upon a small scale, within the compass of an ordinary dial, not mistakable by the eye, not liable to derangement, and out of the reach of tamperings—for its accuracy can be tested at any moment. This desideratum has been accomplished without the aid or intervention of springs, bent tubes, levers, wheel-work, compressed air, elastic bodies yielding to pressure, or any other nicely-fitted philosophical apparatus—beautiful in theory and construction, but insecure and uncertain in practice.

Upon none of these does the Patent Mercurial Gauge depend for its action; but only upon the direct weight of the open Mercurial column, with the single and certain means of registration.

HOPKINSON'S IMPROVED

DIAL PRESSURE GAUGE.

The Dial Gauge shewn in the illustration, is constructed so as to indicate accurately the Pressure of Steam in Boilers. It is made of larger dimensions than is usual with that description of Gauge, and the Figures are legibly marked. It is altogether a superiorly-finished Gauge.

The Figures in the upper circle are to indicate the maximum Pressure at which the Boiler should be worked; so that should the Gauge at any time indicate *more* than is set for by those Figures, any and every observer will know that the Engineer is acting improperly by suffering the Steam to acquire over-pressure.

Price 50s. each.

*** Engineers and Boiler-Makers supplied on the usual terms.

TAPS FOR INDICATORS.

Suitable Taps for the top and bottom of Engine Cylinders are always on hand. These Taps are generally fixed under the radius-bar, so that parties indicating can work the Instrument without loss of time and unnecessary labour. The Taps are fitted with a thread to fit the Indicator, and a screw plug to protect them from injury when not in use—they being intended to be fixtures on the Cylinder.

Price Six Shillings each.

BRITANNIA WORKS, HUDDERSFIELD.

STEAM WHISTLES.

BRASS STEAM WHISTLES ALSO ON HAND.

Price 12s. 6d. each.

WATER GLASSES.

Messrs. HOPKINSON & Co. have pleasure in acquainting Proprietors of Steam Boilers that they have succeeded in improving the annealing of Water Glasses, by a secondary process after they have left the hands of the Glass Manufacturers—which process causes them to be much more durable, and much less liable to be affected by changes of temperature: thus preventing accidents to Firemen, or to those blowing-off.

Price 1¼d. per Inch.

HOPKINSON'S PATENT

MERCURIAL

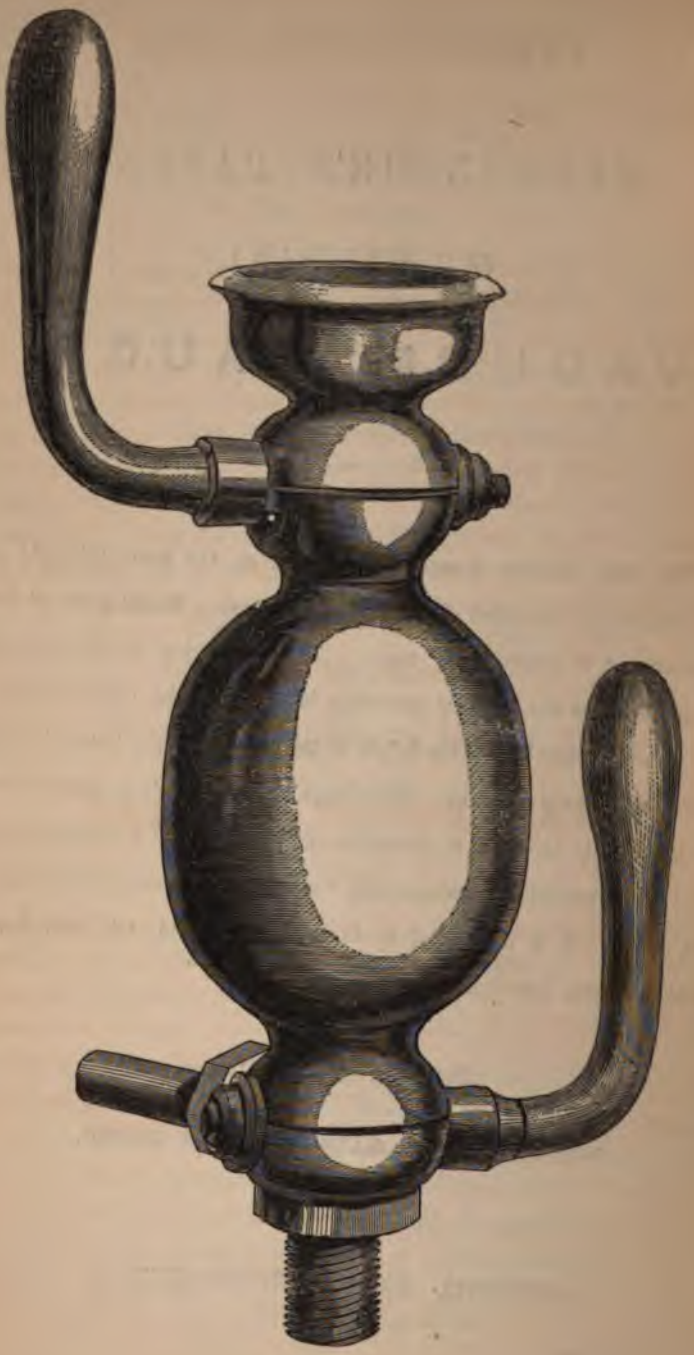
VACUUM GAUGE.

The New Vacuum Gauge is constructed on the same principle as HOPKINSON's Mercurial Column Steam Gauge. Every part of the Instrument is substantially made. The Registering of the Vacuum is produced by the Mercury ascending in an Iron Tube, and descending in a strong Glass Tube—the height of the Mercury in the latter shewing the quality of the Vacuum. The Gauge is warranted to be correct, and it may easily be taken to pieces for examination. It is comparatively free from liability to breakage, and "air-spaces" cannot interfere with its action. It is unequalled in the legibility of its scale, and forms withal a neat Instrument.

Price £2 10s. Complete.

VACUUM DIAL GAUGES, SAME PRICE.

BRITANNIA WORKS, HUDDERSFIELD.



PATENT LUBRICATOR

FOR STATIONARY, LOCOMOTIVE, AND MARINE ENGINE CYLINDERS.

The Patent Lubricator introduced by Messrs. HOPKINSON & Co., is of a simple and effective character, possessing all the necessary qualities required for properly lubricating High or Low-pressure Steam Engine Pistons and Valves. The lubricating matter can be forced into the cylinder at any time, either when the Engine is at work or otherwise, whatever may be the pressure of steam upon the piston. By turning the bottom tap of the Lubricator two separate thoroughfares are opened at the same time, one in connection with the cylinder, and the other in connection with the pressure in the steam-pipe in the Boiler. The latter pressure acts upon the surface of the lubricating matter, and forces it against the interior surface of the cylinder in a spray-like form.

Price £2 2s. each.

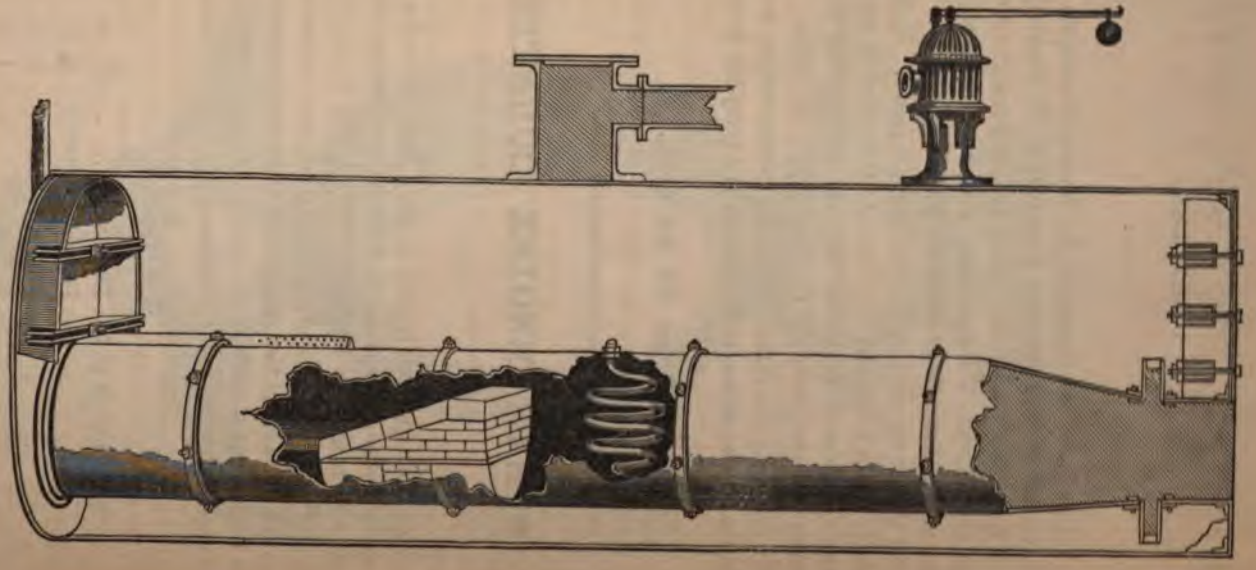
STEAM ENGINE COUNTER.

This ingenious apparatus is made to count from One to Ten Millions of strokes or revolutions, and can be re-set to the starting point in a few seconds. It is used for Stationary, Marine, and Locomotive Engines, and for all classes of Machinery where an accurate registration of speed is required. It enables the manufacturer to ascertain the proper working of his Engine, and to contrast the speed from time to time. It is also a check upon inattention, being a register of the work performed.

PRICES.

To Count up to Ten Thousand	£3	0	0
" " One Hundred Thousand	3	10	0
" " One Million	3	13	0
" " Ten Million	4	0	0

IMPROVED STEAM BOILER.



HOPKINSON'S IMPROVEMENTS

IN

STEAM BOILERS.

THE foregoing Illustration of a Steam Boiler shews HOPKINSON'S Patent Spiral Circulating Pipes attached to the flue behind the bridge, six to ten of which are placed in each flue, according to the length of the Boiler.

Another Improvement is HOPKINSON & RIDING'S method of staying the flues and ends of a Steam Boiler, and providing for the expansion and contraction of the flue, without injury to the Boiler ends or the angle irons. In the Illustration there is shewn four hoops or rings which encircle the flue; these hoops or rings do not touch, nor are they attached to the flue, except by means of bolts or rivets, which are set so that there is a space betwixt the plate and hoop of about one inch. This space allows the water to have free contact with the whole of the surfaces, and prevents that undue thickness of metal exposed to the fire, so objectionable in flues stayed with T iron. The improved hoops or ring-stays can be put together either whole or in segments, and may be again used for a second Boiler.

The staying of the ends is accomplished by riveting a plate on the inside of the end plate of the shell, that plate having slits or spaces for cross plates or bars, of such thickness and width as may be deemed of sufficient strength to bear the pressure brought upon the ends of the Boiler. Bolts or rivets proceed through the end of the Boiler, and are drawn up against a collar on the edge of the plates or bars across the Boiler ends. These prevent the Boiler ends from buckling or going out of form.

Another Improvement is the expansion joint, shewn in the back part of the flue, provided to allow for the expansion and contraction of the flue —in the ordinary construction so very injurious to Boilers, from the sudden heating or cooling, and the various changes in pressure. There is a hoop to which the sides or copper flanches are fixed, which flanches open or compress as required. The bridge, as shewn with an inclined surface, is so formed that the flame and gases may have a free and unobstructed passage into the flue.

It is a serious mistake to make the front of the bridge perpendicular, or at a right angle. An inclined surface not only allows a free passage, but allows the bright fire to be pushed back upon the bridge whilst the furnace is being cleaned, and then drawn back upon the bars.

HOPKINSON'S Valve* is also shewn in elevation on the Boiler. No Boiler should be worked without this valuable appendage. By its use Boiler explosions are rendered impossible.

* See Advertisement.

PATENT STAY PIPES

FOR STRENGTHENING FLUE TUBES OF BOILERS, AND INCREASING THEIR EVAPORATIVE POWER.

THE ordinary Cornish Boiler, with the furnace in the flue tube, and with the steam-pressure on the outer diameter of that flue, is a form of construction which, as experience daily testifies, is liable to change, and to become weaker, according to time and the working-pressure of the steam. This is particularly the case with Cornish Boilers where the flues are of large diameter. Many serious disasters from collapse have arisen from this cause alone.

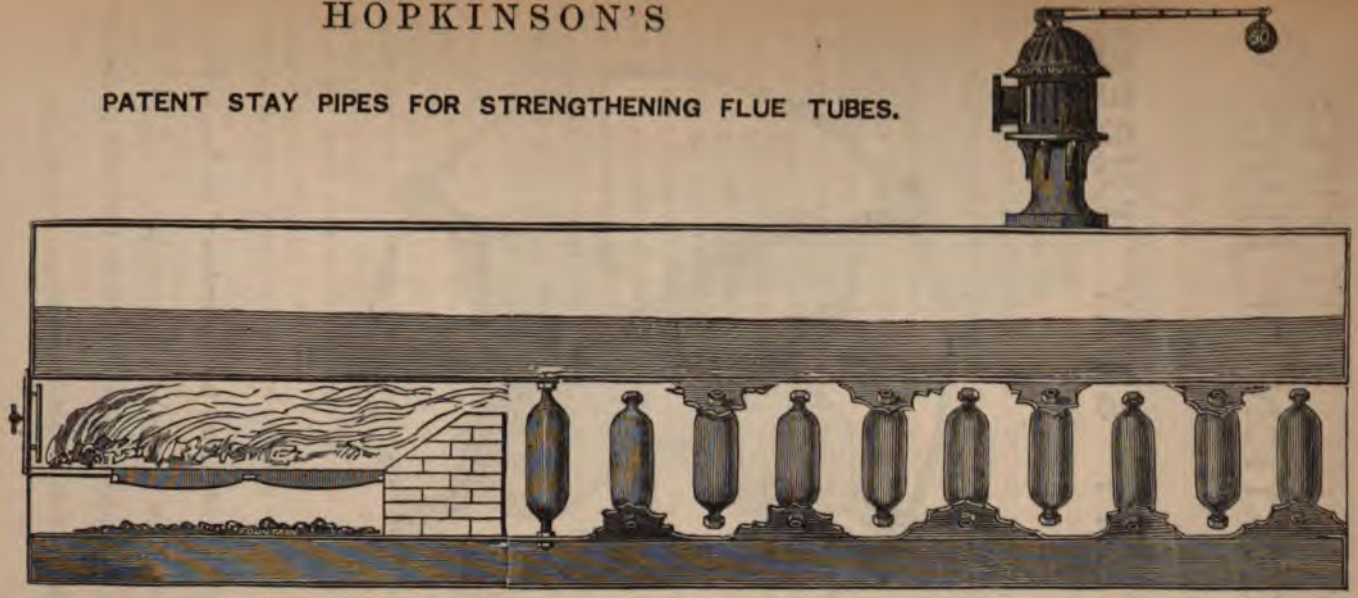
The Patent Stay Pipes, of which illustrations are given on the succeeding pages, (with the mode of their application either to new Boilers, or to old Boilers at work), have been devised for the two-fold object of strengthening this, the weakest portion of the Cornish Boiler, and of greatly increasing the heat-absorbing surface. The Patent Pipes when applied act as a series of props, or stays, against the crushing-in tendency of the pressure exerted on the outer diameter of the flue; thus enabling a flue to resist efficiently a much greater pressure than any flue of the ordinary construction could bear, without that change of form which under ordinary circumstances is constantly taking place—while, as will be seen at a glance, they add in a very appreciable degree to the evaporative power of the Boiler, which in other words, means additional Boiler-power, in quantity of steam generated. By the use of the Patent Tubes, the working-pressure may be increased, if required.

The Patent Stay Pipes may be fixed in any position, and in considerable number—each tube being so much of an addition to the former heat-absorbing surface. They can be applied to old Boilers as well as to new ones. They are fixed with conical collars into taper holes, and well fitted with screws and nuts on the outer-diameter of the flue, so that the latter is kept closely pressed up to the pipes. When thus fixed, the whole flue and pipes or props, together, are framed into one compact mass, capable of resisting any pressure that the outer shell of the Boiler will sustain.

Another advantage arising from the application of the Patent Pipes, is, that *circulation* of the water from the space underneath the flue is thereby secured. The Pipes take in their supply from the bottom, and discharge the highly-heated water at the top of the flue—thus tending to keep an even temperature in the Boiler, and to prevent that uneven expansion which in the ordinary Boiler is known to be very destructive.

HOPKINSON'S

PATENT STAY PIPES FOR STRENGTHENING FLUE TUBES.

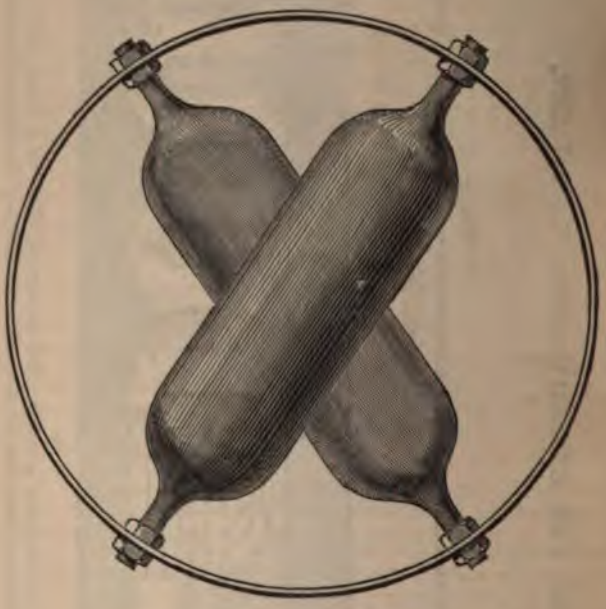


*** This Illustration is in section: and the reader is to *suppose* that the one end of the Stay Tubes, which APPEARS to be unattached, is fixed to the Flue Tube in the same manner as the other end, and as shewn by the enlarged Illustration on the next page.

SECTION OF FLUE

AND

PATENT STAY TUBES.



These Stay Tubes add to the heating surface of the flue, while at t
same time they give increased strength—making the Cornish Boi
applicable for the purposes of higher Steam than hitherto has be
available with that form of construction.

IMPORTANT INVENTION!

STEAM BOILER EXPLOSIONS RENDERED IMPOSSIBLE.

MESSRS. HOPKINSON & CO.'S

NEW PATENT COMPOUND SAFETY VALVE

Is truly what its name imports—a means of safety under all the circumstances which ordinarily produce Boiler Explosions. This Safety Valve cannot be tampered with during the working of the Boiler; it is wholly out of the reach or control of those in charge; it cannot be weighted, except by entering the Boiler—and the Valve possesses the means of instant detection. It is free from all complication, being formed on the simplest principles of construction. Spindles, guides, rubbing surfaces, and valve faces, which are liable to adhere, are all dispensed with in the Compound Safety Valve; nor can the flues become bare of water, by any means, whilst the Boiler is at work.

The action of the Spherical Valve is certain, whenever the steam attains a higher pressure than the limit fixed; and, what is of more importance than all else, whenever the water in the Boiler diminishes below a certain fixed point, the Valve gives timely and unmistakable notice. Should this warning be neglected, the Valve will inevitably open of itself to its full extent, and let off all the steam, discharging an amount of steam equal to an ordinary Steam Valve eight and a half inches in diameter; preventing the Boiler from becoming over-heated, and rendering the continued working under such dangerous circumstances, impossible, and explosions also impossible.

The consequences arising from deficiency of water, negligence, inattention, ignorance, and wilful malice, are therefore amply guarded against.

Upwards of 3,000 are now in use in the principal firms in Lancashire and Yorkshire. They are adopted by Her Majesty's Government, and are largely exported to the Continent.

Deficiency of Water.—"This is evidently the most frequent cause of Explosions; and it is important to provide such means of prevention as will be effective in case of negligence on the part of the fireman. A Safety Valve in connection with a Float, to allow the escape of steam whenever the water falls below the fixed limit, is the best preventive yet known."—*Report of the Chief Inspector of the Association for the Prevention of Steam Boiler Explosions.*

£200 REWARD is hereby offered, and will be paid by the Inventor, to any Person who shall demonstrate the possibility of Exploding a Boiler from pressure of Steam or deficiency of Water, if fitted with the New Patent Compound Safety Valve, provided only that the Boiler operated upon is equal to its ordinary working pressure.

APPLY TO

J. HOPKINSON & Co., Engineers, Britannia Works, Huddersfield.

The Patent Compound Safety Valve is adopted by

HER MAJESTY'S GOVERNMENT,

And by the Governments of France, Russia, Germany, America, & Swed

It has also been adopted, amongst others, by

The following Firms and individual Manufacturers, or Owners o

Steam Engines :—

ANTWERP.

Mr. Wm. Wood

ACCRINGTON.

Watson Brothers
Messrs. Hargreaves and Co.
James Bullough
John Hindle
R. and B. Walmsley
Grafton and Co.
T. Hargreaves
Broadley, Carter, and Co.
Heys and Co.
Mercer and Co.
Dewhurst and Shaw
James Hindle
Mr. Haughton
Brindle and Sons
Swain Rhodes
— Grimshaw
Hindle and Brothers
James Barlow
J. and S. Grimshaw
Stellfox and Taylor
Pearson and Briggs
Haworth and Co.
William Roberts
William Midgeley
John Smith [Enfield]
Marguiss and Green
Rippon and Burton

ASHTON.

Redfearn and Garside
Thomas Neild and Son
Whittaker and Hurst
Mr. F. A. Frost
N. Haward
Cyrus Lees and Brothers

ASHTON—*continued.*

Mr. Stead
John Chadwick
Leyland and Redfearn
Robert Lees
J. and J. Stead
A. and S. Andrew
James Smith Buckley
J. Whittaker

ANNAN—*Scotland.*

Montgomery and Waugh

ALTON—(*near Cheadle.*)

Martin Rourke

BLACKBURN.

Trustees of Mr. Yates
Pilkingtons
Hornby and Co.
Joseph Eccles
Hopwood and Co.
J. Livesey
Brierley and Rodgett
Livesey and Rodgett
Adam Bullough
Sparrows
Baines and Co.
Henry Smithies
H. Wood
William Dickinson
Fielding and Jackson
Lewis Brothers
Firth and Sturdy
Dugdale Brothers and Co.
John Dugdale
William Patison
Harrison and Sons

BLACKBURN—*continued.*

Brigg and Co.
Ordnance Mill Co.
Henry Ward
Yates and Hart
Fielding and Hopwood
T. Parkinson
H. Gilebrand
H. W. H. Graham and Co.
Holden Brothers
John Turner and Co.
Messrs. Duttons
A. W. Patterson
R. Shakleton
John Robinson
Messrs. Dickinson
Decime and Co.
Thomas Holt
Swift and Durham
Rodgett and Co.
Messrs. Dutton and Co.
Messrs. Halstead
Mr. Redmayne
Forrest and Co.
Thomas Bolton and Co.
Thomsons, Belthorn
Bank Top Mill Company
Thomas Carr and Co.
Sagar and Fielding
Hindle and Co.
Shuttleworth and Co.
Copeland and Co.
Bolton and Hall
John and Henry Polding
Messrs. Birtwhistles
Thomas Sherratt
J. Anderson
Hibbert and Co.
Kay and Whalley
W. Stancliffe
J. and W. Halliwell
Railton and Stones
Forrest and Abbott
Dewhurst and Kaye
D. Thwaites and Co.
Corbridge and Cooper
Fisher Street Mill Co.
William and John Yates
W. Forrest
J. Greenwood and Sons
J. and W. Harrison
Kenyon Brothers
Willan and Mills
Pemberton and Co.
Whalley and Billington, Manufacturing Co.
Rishton Victoria Cotton Spinning Co.

BURY.

James Wrigley and Co.
E. Miller and Brothers

BURY—*continued.*

Lomax and Walker
Openshaw Brothers
J. Openshaw, Son, and Co.
Lord Brothers
Tuer, Hodgson, and Hall
Thomas H. Livesey
Warburton and Holker
E. Mucklow
John Whitehead
Messrs. Grundy
Walker and Co.
P. Whitehead and Son
James Openshaw
D. Whitehead and Son
Butterworth and Brook
Fish and Green
Thomas Pilkington and Son
Etc.

BURNLEY.

Hopwood and Sons
Brindle and Sons
J. and J. Sellers
J. Ruley
Marsland and Sons
Pickering Brothers
G. Slater
Keighley and Wood
Lomas and Tunstall
W. Halstead
Messrs. Massey
J. and J. Folds
Henry Dixon
Barnes and Co.
Smith and Watson
J. and J. Roberts
Mr. Lomas
Mr. Hargreaves
Old Corn Mill
Harling and Todd
Kippos Brothers
Corobins and Sons
William Howarth
Hanson and Wood
Henry Knowles and Son
John Kirby
J. Bremand
J. Smallpage
Messrs. Ainsworth
Hurst and Driver
Clivigar Coal Co.
Graham and Shepherd
Haslam and Co.
R. Thompson and Sons
George Keighley
Bracewell and Griffiths
Thomas Veevers
George Eastwood
Berry and Son
Sutcliffe and Son

BURNLEY—*continued.*

Dewhurst and Co.
John Butterworth
J. and J. Walton
H. and E. Rawlinson
H. Sutcliffe
Wm. Wilson and Sons
Parker and Watkinson
Asalam and Veevers
Mr. Sager
Bury and Sons

BOLTON.

Blair and Sumner
Benjamin Hick and Son
J. and G. Knowles
Cross and Son
Crook and Sons
Arrowsmiths
Thomasson and Sons
Heaton Brothers
Musgrave and Sons
Horwich Printing Co.
Gorse and Thompson
J. Hodgkinson and Co.
William Tristram
Crowley and Co.
Holden and Co.
Harwood Brothers
Daniel Latham

BRADFORD.

Oates, Ingham, and Sons
Addison and Son
James Dalby
Mr. Allan
Robert Sutcliffe
Samuel Sutcliffe
Holdsworth and Sons
Hutton, Thornton, and Co.
Smithson and Co.
Craven and Co.
Leather and Co.
Fortune and Lancaster
Mr. Duncan [Rewden]

BINGLEY.

Sharpe and Sons
Hargreaves and Sons
Shepley
Foster and Sons
James Anderton
Smith and Etson
H. and J. Wright

BATLEY.

Jubb and Brothers
Bagshaw and Sons
Bowling and Co.
M. Sheard and Sons
Jno. Colbeck and Son

BATLEY—*continued.*

Squire Denton
Wildsmith and Carter
Sanderson Bros.
Fox and Ibbetson
Jno. Jubb and Sons
Joseph Jubb and Sons
D. Ramsden [Batley Carr]
J. Colbeck
Robert Brearly and Sons
William Dean

BIRMINGHAM.

Brinton and Son

BACUP.

Smith and Sons
Haworth Brothers
G. C. Harrison
Rossendale Industrial Co.
J. Barker and Son
Sutcliffe Bros.
Williams and Sons

BARNSLEY.

J Barraclough and Sons
Barnsley Water Works Co.

BRIGHOUSE.

William Burrow
John Burgess
Thomas Blackburn
Sugden and Son
Brook's Corn Mill
Rayner and Co.
Firth, Riley, and Co.
M. Waller and Sons
Thomas Blackburn
Noble, Broscombe and Ainley

BRISTOL.

F. W. Green
Carr's Mill Co.
Fearnley, Hellawell and Co.

BAMBER BRIDGE.

G. and R. Dewhirst
R. Eccles and Co.

BRIDGENORTH.

Water Works Co.

BARNOLDSWICK.

Wm. Bracewell

CHORLEY.

C. Wood and Sons
Messrs. Withnell
Mr. Parker
Messrs. Parkes
J. Hodgkinson and Co.
Smalley, Sykes and Co.

List of Firms using Hopkinson's Patent Safety Valve.

CLAPTON—(*Middlesex*).

J. W. Mott

CLECKHEATON.

Anderton and Son
Exors. of Mr. Broadbent
Messrs. Goldthorpe
William Kershaw [Gomersall]
John Shaw

CARLISLE.

Slater and Co.
Cowan and Sons
J. D. Hewson and Co.
John Dalton and Sons

COLNE.

Walk Mill Co.
John Bannister
Richard Ord
Jno. Lonsdale and Co.
Horsfield and Co.

COVENTRY.

Thomas Townsend

CLITHEROE.

Mercer Brothers
Bracewell Brothers
A. W. and R. Dewhurst
Hargreaves and Ingham
Robinson, Dickenson, and Co.
James Fearnley
Henry Heald
Isherwood, Brown, and Thompson
Mercer and Co. Print Works

CHESTER.

F. A. Frost and Son

CONGLETON.

Pearson and Sons

DARWEN.

Eccles and Shorreck
J. Wardley
Mr. Gilburn
Messrs. Gregson
Nicholls and Ashton
Catlow and Tomlinson
John Leach
E. C. and J. G. Potter
Heron, Baron, and Eddleston
Messrs. Kenyon
John Walmsley
George Wood and Co.
Pearson, Wood, and Co.
N. Walsh
J. Garstang
A. Bullough
Jos. Leach
Parson, Kay and Co.

DERBY.

Walter Evans and Co.

DUCKINFIELD.

J. Chadwick and Co.
Hyde, Sons, and Sowerby
Messrs. Garforth, Engineers
Fernihough and Sons
Robert Lees
Ely Cryer
C. Bradbury

DINTING.

Edward Potter and Co.

DROYLSDEN.

Edward Cryer
Lees and Holman

DARLINGTON.

H. Pease and Co.

DENHOLME.

Samuel Balme and Sons
Foster and Sons

DEWSBURY.

Jas. Wooller and Sons

ELLAND.

J. and J. Ferrars
Luke Crossley
Maude and Riley
Crossley and Sons
Richard Marsden
Dyson and Shaw
Henry Mitchell
J. Dyson

EARBY.

C. Bracewell Brothers

EDINBURGH.

Messrs. Meronies

EDENFIELD.

J. Rostron

FROME.

J. Holroyd

FAILSWORTH.

Frank Hall

FLEETWOOD.

Richard Hyan Steam Corn Mills

GLASGOW.

Gorrick, Rope, and Co.
Lancefield Spinning Co.
J. and W. Scott
A. and A. Gallworth
Todd and Higginbottom
J. Donnie and Co.

ist of Firms using Hopkinson's Patent Safety Valve.

HULL.

l Sons
ooke
Villows

BDEN BRIDGE.

o.
, and Co.
Sons
l Son
ker and Son
and Son

ger

IORSFORTH.

ASLINGDEN.

r and Sons

HADFIELD.

idebottom
ottom and Bros.
debottom
des
ottom
Edward Platt

CKMONDWIKE.

d Son
nd

VY BRIDGE.

n

DERMINSTER.

Naylor
y and Son

KEIGHLEY.

Sellers
and Co.
d Son
Mariner
gh
and Sons
d Sons
ell

and Sons
and Sons
iver

LANCASTER.

North Western Railway Co.
son

LITTLEBOROUGH.

Newall Brothers

LIVERPOOL.

Joseph Martin
Messrs. Fairie
Vauxhall Distillery Co.
Liverpool and North Flour and Rice Mill Co.
Sampson Moore
Messrs. Jagger, (Refiners)
Lang and Rea

LEEK—*(Staffordshire).*

Anthony Ward

LUDDENDEN-FOOT.

R. Whitworth and Co.
Thompson Brothers
John Ambler
Bracken and Sons

LEEDS.

J. Dodgson and Co.
R. Wood and Sons
Hodgsons
E. B. Wilson and Co.
Littles, Cousins, and Leach
William Webster
Samuel Kirk and Sons
Robson and Bucktrout
Wm. Denton [Gipton Wood]
Jas. Lethley [Gildersome]
K. Wolstenholme
Leeds Industrial Co-operative Flour and Provision Society

LEIGH.

J. and J. Heys

MANCHESTER.

Lightboun, Aspinal, and Co.
W. Berry
John Lancaster
William Morris
T. Hoyle
Worrall and Co.
Mathers and Co.
Peel, Williams, and Peel
Matley and Scholes
J. and G. Galloway
John Johnson and Sons
T. Holcroft
Bradford Iron Works
J. and L. Gray
Messrs. Blundritt
Langworthy Brothers
Sharp, Murray, and Co.
William Fairbairn and Sons
P. and R. Jackson, Salford Rolling Mills

List of Firms using Hopkinson's Patent Safety Valve.

MOTTRAM.

Henry Lees

MOSSLEY.

R. H. Buckley
F. Howard and Son
John Shaw
John Schofield
Peter Shaw

MACCLESFIELD.

James Fielding
J. and T. Brocklehurst and Sons

MAIDSTONE.

William Simpson

MANSFIELD.

W. Hollins and Co.

NORTHOWRAM.

R. Midgley

NEWLAY.

Haigh and Billington

NORWICH.

Delani, Magnay, and Co.

NEWCASTLE-ON-TYNE.

Hawthorn and Co.
I. Thompson and Co.

NEWCASTLE-UNDER-LYNE.

S. W. Dawson

NEWTON—*(near Warrington).*

Willespie and Mason

NEWTON HEATH.

Dixon and Nightingale

NEWCHURCH.

John Barcroft
George Howarth

MARSDEN.

Taylor and Hirst

OTLEY.

Messrs. Garnett

OVENDEN.

Joshua Appleyard, Esq.

OLDHAM.

Greaves and Son
Radcliffe and Son
Warburton and Taylor
Hibberts and Platts

OLDHAM—*continued.*

Mr. Retford
Jones and Co.
Mr. Clegg
James Lees and Sons
Joseph Clegg
Joseph Buckley
Richard Shiers
William Taylor and Brother
J. Pritchard and Sons
J. Whitehead and Co.
Buckley and Seville

ORMSKIRK.

John Fairhurst and Son
Moor Street Corn Mill

OSSETT.

Lancashire and Yorkshire Cotton Co.
Jno. Earnshaw

OPENSHAW.

John Orrell and Co.

PRESTON.

Horrocks, Miller, and Co.
D. Arkwright
Swainson, Birley, and Co.
Smith and Slater
W. Simpson
Napier and Goodair
R. Ogden and Co.
John Stephenson
Joseph Clayton
Goodair, Slater, and Smith
John and Thomas Goodair
G. Eastham
John Maynard
Jesper Brothers
Whitworth and Barrett
G. Whittle
James Parker
Simon Bond
Robert Hind

PENISTONE.

G. and W. Waites

PADIHAM.

Watson and Cherbun
Knowles and Duckworth
Read Building Co.

PATRICROFT.

Naysmith and Co.
Oswaldtwistle Commercial Co.

PEMBERTON.

Roper, Leyland, and Marsden

RAMSBOTTOM.

J. Ramsbottom and Co.
Ashton Brothers
Porritt Brothers, and Austin

ROCHDALE.

— Ashworth
Richard Walker
R. and D. Howarth
Woolner Brothers
Castleton Print Works
Thomas Brockie
— Duckworth

RETFORD—*(Notts).*

J. H. Waddington

RASTRICK.

— Helms
B. and J. Walker

RADCLIFFE-BRIDGE.

William Allen

ROYTON.

H. Whittaker and Sons
John Buckley
John Holden and Co.

RIPPONDEN.

Calder Cotton Commercial Co.

RAWTENSTALL.

P. H. Whitehead and Co.
Porritt, Bro., and Austin
Joseph Wood Whitehead

ROTHERHAM.

J. and J. Habershon and Sons
Samuel Beale
Guest and Chrimes
William Widdison
Messrs. Yates
William Corbett
Perry, Smith and Co.
George Appleyard
William Owen

SWINTON.

Samuel Barker and Son

SELBY.

William Liversedge

SHEFFIELD.

W. H. Brown
Naylor, Vickers, and Co.
Henry Hoole and Co.
Thomas Firth and Sons
United Gas Co.
Norton, Simmons, and Ward

SHEFFIELD—*continued.*

Parker and Co.
Crowley and Co.
John Charles and Sons
Easterbrook and Allcard
Truswell and Co.
Jno. Brown and Co.
W. and S. Butcher
Crooker, Roberts and Co.
Shortridge, Howel and Co.
Spear and Jackson

STANNINGLEY.

Joseph Butler and Sons.

STALEY-BRIDGE.

Harrison and Sons
Sidebottom Brothers
Bailey Brothers
Bayley and Sons
Hugh Shaw
Adshead Brothers
Adshead and Co.
James Hall and Son
Albert Hall
Johnson and Co.
— Chadwick
Staley-bridge Mill Co.
H. Johnsons and Sons

SHIPLEY.

Hargreaves Brothers

STOCKPORT.

H. Hanson
Kershaw, Lees, and Co.
Marshall and Sons
C. and T. Bailey
C. Howard and Co.
S. Morris
Cheadle Print Works
R. and D. Shepley [Marple]
G. Andrew and Sons
Sharples and Co. [Marple]
Jno. Walthew

SOWERBY-BRIDGE.

Thomas Nicholl
Thomas Morley
Thomas Fielding
J. Wood and Sons
James Crossley
Messrs. Edwards
W. and H. Rawson
John Sutcliffe
Thwaites and Co.
— Nicholl
James Clay and Sons
Shepherd, Whiteley, and Blackburn
James Greenwood
Sowerby-bridge Flour Society
Morley and Sons

List of Firms using Hopkinson's Patent Safety Valve.

STAINLAND.

John Shaw and Sons
Mellor and Son
Sykes and Sons

STORTON.

Hopwood and Son

SKIPTON.

Thomas Fletcher
Bell and Parker
Shacklock and Sons
James Hartley
William Parke

STACKSTEADS.

New Bacup and Wardle Commercial Co.

SETTLE.

Thomas Proctor
Levi Towler [Burton in Lonsdale]

TODMORDEN.

Firth and Haworth
Lord Brothers
Brown and Stead
Lacy Brothers
John Buckley
Fielding Brothers
Barker and Shackleton
James Barker and Sons
John Collinge and Co.
R. Mills
Barker and Sutcliffe
William Clegg

TODMORDEN—*continued.*

— Pickles
Law and Dawson
Shepherd and Sutcliffe
Astin and Barker
— Mitchell
John Helliwell
Heap, Ashworth, and Fielden
Todmorden Gas Works
Redman and Co.
W. Howarth
— Fielden
Todmorden and Cornholme Bobbin Co.
Sutcliffe and Sons
Horsfield and Stephenson
Greenwood, Newall, and Sutcliffe [Walsden]
Todmorden Flour Co.
Exors. of Mr. Bottomley [Walsden]

WHALLEY.

Thomson and Son

WIGAN.

Haigh Foundry Co.
Walley, Thomson, and Barrett
Taylor and Brothers
Ince Hall Colliery Co.

WEDNESBURY.

Whitehouse and Co.

WARRINGTON.

Smith and Haughton
John Needham

TESTIMONIALS.

The following Testimonials to the efficiency of Hopkinson's Patent Compound Safety Valves are selected from upwards of three hundred letters, received from the chief Owners, or Workers of Steam Boilers, in Lancashire, Yorkshire, and other Counties.

SHEARD & SONS, Batley.

"We have five of your Safety Valves. The first was put on about twenty months since. We believe if not meddled with, they will act well, and secure perfect safety. One of ours was certainly the means of avoiding an explosion, by blowing off the steam when the water got too low."

T. TUNSTALL, Burnley.

"We have had your Valves at work for about three years, during which time they have given us every satisfaction. We believe them to be the best Valves at present out, and their action almost as certain as death. We know no instance in which ours have failed to blow off for either increase of pressure or low water."

REDFERN & GARSIDE, Ashton-under-Lyne.

"We have much pleasure in testifying to the efficacy of the Safety Valves. We have at present in use two of these Valves on two 60-horse Boilers at 50lbs pressure, though originally we worked them at 30lbs. The Valves have been at work for eight years; and our Engineer, some six months ago, made the experiment with bare flues, full fires, with water going in at 100 degrees, and found it impossible to make more steam than the Valves would carry away. We think them the best Valves out, and think it impossible for any Boiler to burst with them on."

DEWHURST & SHAW, Accrington.

"The Valves have been fixed on our Boilers five years, and have been found very efficient. The have saved us twice from explosion from deficiency of water. We can recommend the Valves with confidence to all persons wishing to place their Boilers safe."

JNO. CROSSLEY & SONS, Halifax.

"We have used your Patent Safety Valves for the last eight or nine years, and we have at present 27 of them applied in our Works. They have answered their purpose better than anything we have tried before, and we recommend them as the best contrivance we know of."

JAMES BARLOW, Accrington.

"I am perfectly satisfied with the working of your Valve. Indeed, I would not be without it for ten times the money. Throughout the greater part of Lancashire it is adopted, and considered perfect for its purpose."

F. A. FROST, Ashton-under-Lyne.

"I placed one of your Valves on a new Boiler, seven years ago. It is very sensitive in its action, and not liable to get out of order, as is proved by the fact that mine has never been cleaned or adjusted since I had it. I consider it the best Valve I have ever seen. Some years ago, when my brothers saw it, they removed all their old Safety Valves, and placed one of yours on each Boiler."

Testimonials.

HARGREAVES & Co., Accrington.

"We beg to say that we have six large Boilers, each of which is fitted with one of Hopkinson's Safety Valves, which we consider the best in existence, and which we would not be without on any consideration. We are convinced that if they were in general use, the number of accidents from Boiler explosions would be reduced to a merely nominal figure."

W. ROBERTS, Accrington.

"I have tried your Valve several times for over-pressure of steam. I have also had the water very low in the Boiler. The efficiency of the Valves in all the cases was shewn by the escape of immense volumes of steam, until we got the steam to the proper pressure, or got the water to its right level. Then the Valve was again quite close."

J. S. BUCKLEY, Ashton-under-Lyne.

"Your Valve answers exceedingly well, and gives us every satisfaction. It is a first-rate thing, and, in my estimation, cannot be surpassed. I have heard it praised by many Engineers."

E. RODGETT & Co., Blackburn.

"We have great pleasure in stating that your Valves have given us every satisfaction. They blow off with certainty, either for low water or high steam. They cannot be tampered with by the Engineman; and we recommend them to all owners of Boilers as the most efficient Valve yet introduced."

SHUTTLEWORTH & Co., Blackburn.

"Hopkinson's Safety Valve gives us the greatest satisfaction. Its efficacy has been proved on various occasions, within the last nine months, and in each case gave proof of its worth—it is the only Valve at present known to us that we shall use."

FORREST & Co., Blackburn.

"We consider Hopkinson's Compound Safety Valve to be the best and safest that can be applied. We have had four working since 1859. They are never out of order; and after being once set, cannot be tampered with during the working of the Boiler, either by our Fireman or any other person. We should never think of working a Boiler without one. We can confidently recommend them. We started our Boilers at 18lbs pressure, but with more machinery on, we are now working at 45lbs pressure, and they answer quite as well at the higher pressure as at the lower."

CHARLES SWIFT & Co., Blackburn.

"During the time the Valves have been in use, viz: eight or nine years, I have not heard of a single complaint."

BRACEWELL, BROTHERS, Earby, near Skipton.

"Hopkinson's Valves we consider to be the best yet brought out—simple and effective. Some of ours have been working for years."

HILL & SONS, Victoria Boiler Works, Heywood.

"We have fitted your Valve to a large number of Boilers in various parts of the country. We have a very good opinion of it, and think it the best Safety Valve that has been brought under our notice."

ANDERTON & SON, Cleckheaton.

"We have had Hopkinson's Safety Valve in operation for some years—say three or four. We believe that no Valve can surpass it for efficacy. It has never been out of working order, and always indicates danger. We cannot see how it is possible for it not to act well."

Testimonials.

BARNES & FIELDING, Burnley.

"We applied four of your Valves about six years ago, and are glad to say they act very correctly. They give us every satisfaction, and we can recommend them in preference to any other."

JAMES & Co., Hull.

"It is two years since we applied your Valves, during which time we have always found them to work efficiently. We, therefore, now have full confidence in them."

C. WOOD, Brinscall, near Chorley.

"We have had Hopkinson's Safety Valve for the last seven years on a high-pressure Boiler (50lbs), and have always found it correct—blowing off the moment the water was low, or when the pressure exceeded the fixed limit."

SLATER & Co., Carlisle.

"After the experience of four-and-a-half years, we consider the Valves to be most excellent and trustworthy. Their working has never given us the least trouble."

JAMES BURROW, Brighouse.

"I have for the last eight years been using one of Hopkinson's Compound Safety Valves for my Boiler, and during the whole of that time it has never missed acting. It is no worse now than it was the first day in was put on."

WALTER EVANS & Co., Derby.

"The Valves appear to be very efficacious. They allow of the escape of steam immediately the pressure becomes too high, or the water is allowed to get too low in the Boiler."

A. MIDGLEY, Accrington.

"I can speak with the greatest confidence of Hopkinson's Patent Safety Valve, not so much from my own experience of it, as I have only had it in use about twelve months, but from the experience of others of my acquaintance who have had it in use for a much longer time. So far as I have ever heard from a large circle of acquaintance, I have never yet heard an objection raised to it by any one. That says a great deal for it, as few inventions, however good, but will find one or another raising some kind of objection. I believe it impossible, by any ordinary means, to burst a Boiler having this Valve on."

JOHN HINDLE, Accrington.

"I have had one of Hopkinson's Safety Valves at work for four or five years, and it works well. It has had no repairs, nor given any trouble, but seems to answer as well as at first."

BROADLEY, CARTER & Co., Accrington.

"The first Valve we had has been worked six years—the second, four years—and the third, eighteen months. Up to the present time they have never been out of working order. We are very well satisfied with them."

LEWIS BROTHERS, Blackburn.

"We are quite satisfied with the Valves. They allow the steam to escape when the Boiler is short of water, and when the pressure of the steam is too great. They perform their duty efficiently."

GOODAIR, SLATER, & SMITH, Preston.

"We would not now like to be without the Valves, as we consider them the best protection against damage through scarcity, or lowness, of water, ever invented."

Testimonials.

FAIRHURST & SON, Ormskirk.

"Our opinion is very strong in favour of Hopkinson's Compound Safety Valve, and we would not be without one on our Steam Boiler on any account. We have frequently seen the Valve tested, when the pump has been out of order; and the Valve has never once failed to indicate the short supply of water, which it keeps no secret. The Valve has never been out of order since we had it—ten years ago, nor do we see any part likely to get out of order. We are decidedly of opinion that Boiler explosions would be prevented if this Valve were generally used."

PEASE & Co., Darlington Mills.

"The Valve has been at work six months, and so far has given us every satisfaction. We adopted the Valve on the strong recommendation of the Association for the Prevention of Steam Boiler Explosions, at Manchester."

J. & S. GRIMSHAW, Accrington.

"We can confidently say that it is the best Valve we ever tried."

JOHN BAYNES, Blackburn.

"I have adopted Hopkinson's Valve to all my Steam Boilers. They have been at work four or five years, and I consider them the most efficient Valves in use."

WHITEHEAD & SONS, Greenfield, near Manchester.

"We have had in use two of Hopkinson's Valves from four to five years, and are much pleased with their action. When the steam is below the working pressure, we have none blowing to waste; and they give notice immediately the water gets below the working pressure, before it becomes dangerous to work."

BRINDLE & SON, Accrington.

"We think there is not a better Valve out."

BARKER & SONS, Bacup.

"Our opinion is, that the Valve is a good one. We have applied several, and from no party have we heard any complaints."

W. & H. FOSTER, Bingley.

"We can confidently recommend the Valves, having never yet known one of them fail in the purposes for which they are adapted."

R. & D. HOWARTH, Rochdale.

"We have applied Hopkinson's Compound Safety Valve to nearly all the Steam Boilers we have made for the last ten years. We have invariably found the Valves to answer well, and give entire satisfaction to the users."

G. & W. WAITES, Penistone.

"Should we have more Valves to fit, we should use Hopkinson's in preference to any other."

WALKER & LOMAX, Bury.

"We think yours the best Safety Valves in use."

WHITTAKER & SONS, Haslingden, near Manchester.

"We consider yours the best Safety Valve we have seen."

HAWORTH BROTHERS, Bacup.

"We tried your Valve to two or three Boilers first, and liked them so well that we have applied them to all. We consider the Valves to be efficient, and a great security, in preventing explosions and accidents. There is very little trouble with them."

Testimonials.

FROST & SONS, Chester.

"The Valves have given us every satisfaction. We have had them at work about four years, and have never had any trouble with them."

R. ARROWSMITH & Co., Gilnow Mills.

"Three of your Valves have been in work upwards of four years and have given us satisfaction."

BELL & PARKERS, Eastly, near Skipton.

"We can strongly recommend the Valve to all parties using steam-power."

CRAVEN & Co., Bradford.

"We are exceedingly satisfied with the Valve, and think there can be no doubt as to its great value."

PLATT BROTHERS, Oldham.

"We believe yours to be a good Valve in all respects, and it meets with general commendation."

HOPWOOD & SON, Burnley.

"We have three of Hopkinson's Valves at work here for six or seven years. We have found them quite trustworthy."

BRACEWELL & GRIFFITH, Burnley.

"We have supplied to our customers a great many of Hopkinson's Valves, because we think they are the best out."

H. & E. RAWLINSON, Burnley.

"We have not had the least trouble with the Valves since they commenced. They answer their purpose exceedingly well—to our perfect satisfaction."

WARBURTON & Co., Bury.

"We have had three of the Safety Valves fitted, which have been in use for the last six years. There is no trouble attending them. In fact they are considered by us as first-class Valves."

ABBOTT & FORREST, Blackburn.

"We find the Valves to answer all the purposes for which they are intended."

TAYLOR BROTHERS, Shaw, near Oldham.

"We got the first of Hopkinson's Valves in 1859, and were very soon convinced of its safety and efficiency—so much so, that we got all the Boilers we have fitted-up with them, and would not exchange them for any others that we have seen."

PILKINGTON & SON, Bury.

"We consider yours to be one of the most perfect Valves in use."

MONTGOMERY & WAUGH, Annan.

"We can unhesitatingly vouch for the efficacy of your Valve as we have found it to be so in every respect."

HINDLE BROTHERS, Accrington.

"The Valves have always worked in a highly satisfactory manner."

Testimonials.

MILNER & SOWERBY, Halifax.

"We consider the Valve to be equal to all that Mr. Hopkinson states it will do. We have enquired of our Engineer his opinion, and he states that there is no other Valve equal to it, to his knowledge; and he has heard of no accident where these Valves are in use."

JOHN BARCROFT, Esq., Rossendale.

"I have had one of Hopkinson's Valves attached to my Boiler about two years, and can recommend it for safety, as being the best Valve in use. I have seen a great many Valves, but none so good as Hopkinson's. I think that it is impossible for a Boiler to explode with one of these Valves on, either from over-pressure, or from being short of water."

H. W. H. GRAHAM, Esq., Mill Hill, near Blackburn.

"I have used Hopkinson's Safety Valves for four years. They have given entire satisfaction. Had I a hundred Boilers, I would apply one to each. I believe nothing can be found to surpass, if anything to equal them. I have two in use on 40-horse Boilers. My works, on more occasions than one, when the Boilers were short of water, have been stopped by the action of these Valves."

R. THOMPSON & SONS, Whalley.

"Two of your Valves have been at work about seven years, and the other one about a year-and-a-half—and we always found them to work correctly. In fact, we would not have a Boiler working without them."

TOWNSEND & SON, Coventry.

"We have had four of your Valves in work for the last six or seven years, during which time not one of them has been out of order, or required any attention. They answer admirably, and we can strongly recommend them."

J. HOLROYD, Esq., Frome.

"If I were to have twenty Boilers, I would have one of your Valves on each. It is safe and simple; and the Stoker cannot tamper with it. I have reason to be thankful I had one on my Boiler. I can with confidence recommend the article."

HENRY LEES, Esq., Hadfield, near Manchester.

"We have had one of your Valves in constant work since June, 1856, and have found it to work satisfactorily, indicating high and low water, as well as excess of steam. We consider the Valve, when properly fixed and adjusted, to be as trustworthy as any Valve we know of."

TODD & HIGGINBOTTOM, Glasgow.

"We have had Hopkinson's Safety Valves working upon five of our Boilers, for six or seven years, and we have since applied the Valve to two or three other Boilers. We have every reason to speak well of the effectiveness of the Valve. When properly set and arranged, it never fails to act, both as an indicator of too high pressure in the Boiler and of a deficiency of water. We should not like to be without it on any of our Boilers."

HOLDEN & Co., Bolton.

"We are quite satisfied with the Valve in every respect. It is efficient, giving instant notice of either a short supply of water or too great a pressure of steam. It is more than likely we shall put down an additional Boiler, and shall certainly have one of your Valves affixed."

WARD & Co., Leeds.

"We have always found the Valve to act well. Indeed we would not be without it, as we believe it renders the Engine-driver more cautious, giving as it does, immediate alarm, if the steam is too high or the water too low."

THOMAS COPELAND, Esq., Blackburn.

"Hopkinson's Compound Safety Valve is considered the best Safety Valve we have in these parts."

SAGER & FIELDING, Blackburn.

"We think the Valve a first-class invention, with regard to safety."

JOHN BANISTER, Esq., Burnley.

"I can with confidence, after one year and eleven months experience, recommend Hopkinson's Safety Valve. It is in reality as good in every respect as Mr. Hopkinson represents it to be."

J. D. HEWSON & Co., Carlisle.

"We are informed they are the best Safety Valves in use."

LITTLE, LEACH & Co., Leeds.

"We are now replacing our old Low-pressure Boilers with new High-pressure ones, which we should not consider complete without one of Hopkinson's Valves. These Valves are a protection against too high steam and too low water, and cannot be tampered with whilst the Boiler is working. We may add, that since we have had them, we have felt ourselves almost totally insured against accident. From their extreme simplicity, we do not see that they can get out of order."

H. HOOLE & Co., Sheffield.

"We have had your Valve in use for about seven years. It acts well, and has had nothing done to it since it was affixed."

DARLING & SELLERS, Keighley.

"We can confidently recommend the Safety Valve. We have tried it several times—letting the water get too low, and found it to answer the purpose stated. In every other thing it answers the same purpose as an ordinary Safety Valve,—with this advantage, it cannot be tampered with."

JOHN WATSON, Esq., Burnley.

"My Fireman has never found anything wrong with your Valve since it was first applied, five years ago. It appears to answer every purpose for which a Safety Valve is necessary."

DELANI, MAGNEY & Co., Norwich.

"We can confidently recommend your Valves. They are very simple, and cannot be tampered with."

T. WOOLER & BROTHERS, Blue Pits.

"We consider the Valves to be perfectly effectual, either in case of shortness of water or too high pressure."

JOSEPH HALL, Failsworth.

"We have been using the Valves for seven years, and find them everything we should wish for. In fact, the expense upon them for the time above stated can scarcely be put down at five shillings."

Testimonials.

FIRTH & HAWORTH, Todmorden.

"We think well of the Valves, and believe that with them on a Boiler there is danger of an explosion."

W. ALSTON & Co., Blackburn.

"We have two Boilers, upon each of which is fitted Hopkinson's Safety Valve. Boilers were put in in 1856, so the Valves have been on and at work for five y They have given every satisfaction, and have not once been out of order."

H. WHITAKER & SONS, Royton.

"We have two of the Valves, one on each Boiler. We work up to a pressu 56lbs to the inch, and feel much more confidence with them than we should with other we know of. They are very tickle, and act very promptly, both with high s and also for lowness of water in the Boiler, which makes us feel quite easy as to the s of our Boilers."

TUER & HALL, Bury.

"With our machinery we have sent scores of the above Valves, and as yet we not heard a single complaint."

E. RODGETT & Co., Blackburn.

"We are fully satisfied with the Valves. We do not know any other Valv entirely preventive of accidents, from over-pressure of steam or want of water."

C. HOWARD & Co., Stockport.

"We are well satisfied with Hopkinson's Safety Valves, and would not have a B without them."

Printed by B. Brown, Market-place Corner, Huddersfield.

ER HS

Nov 2 - 1932